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A COMPUTER-AIDED DECISION STRUCTURING PROCESS.(U)

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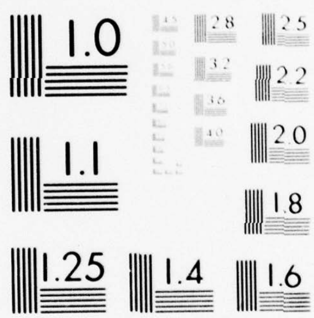

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A COMPUTER-AIDED DECISION STRUCTURING PROCESS

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Final Report

June 1979

Prepared for:

OPERATIONAL DECISION AIDS PROJECT
(Codes 431, 434, 437, 455)
Office of Naval Research
Department of the Navy
Arlington, Virginia 22217

Contract No. N00014-78-C-0175

SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 326-6200
Cable: SRI INTL MNP
TWX: 910-373-1246

SRI International

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June 1979

By: MILEY W. MERKHOFER
BURKE E. ROBINSON
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A computer-assisted, step-by-step procedure is being developed for establishing the basic structure of a decision problem. Initial steps elicit a preliminary decision structure, subsequent steps are designed to identify and expand the analysis of those areas to which the decision is

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most sensitive. The output of the process is a quantitative decision model. An interactive computer program with graphics for implementing the procedure is partially completed and will be evaluated using typical warfare scenarios.

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1. INTRODUCTION

SRI International's Decision Analysis Group is conducting research on decision structuring for the Operational Decision Aids (ODA) Program of the Office of Naval Research. The goal of SRI's research effort is to develop a computer-assisted decision structuring process for use by a naval task force commander (TFC) and his staff and to implement the associated computer aids on the ODA test bed. Research to date has resulted in the design and partial computer implementation of a decision structuring procedure. The structuring procedure and recent progress toward completing its implementation are described in this report.

1.1 ODA Program Background

The ODA Program was initiated in 1974 as an interdisciplinary effort designed to apply advances in four professional areas to the development of navy command and control systems. The four areas contributing to the effort have been computer science, decision analysis, systems analysis, and organizational psychology. The effort has focused on developing decision aids for application to decisions at the level of the TFC, and the approach has been to contract for the development of specific products from a variety of contractors.

In addition to the SRI decision structuring aid, decision aids already developed or currently being developed within the Program include aids that address information processing [1,2,3], man-machine communication [4,5], military outcome estimation [6,7,8], and nomography and uncertainty analysis [9]. As the various aids are developed, they are being programmed and installed on a test bed in the Department of Decision Sciences of the Wharton School, University of Pennsylvania. The purpose of the test bed has been to provide a central experimental site for aid evaluation. An underlying assumption of the research program has been that all products should be subjected to objective experimental testing to evaluate their usefulness as operational decision aids for naval decision making.

1.2 Need for Structuring Aids

Decision structuring is the process of identifying and organizing the factors of a decision in such a way that logic may be applied to identify a preferred decision strategy. Decision structuring is usually easy for the TFC. Most of his decisions are familiar and readily dealt with by existing personal and organizational problem-solving mechanisms. Occasionally, however, the TFC will encounter an important decision that is difficult because of its complexity, its unfamiliarity, or both. When little time is available for deciding, this can create stress that significantly degrades decision-making ability. For these situations, aids are needed to help the TFC structure relevant information into a formal model whose analysis will help identify the most desirable course of action.

1.2.1 Prestructured Models

One approach for reducing the problems associated with unstructured decisions is to provide the TFC with prestructured models. In a prestructured model, the relevant factors and relationships for a specific class of situations that may be encountered are identified and modeled in advance. These models are then programmed on a computer to provide the TFC with a convenient means for simulating the outcomes of alternative courses of action. In some implementations, the models can be used to optimize an action according to some criterion function.

Many of the decision aids currently under development within the ODA Program can be regarded as prestructured models. These aids attempt to capture the issues surrounding one particular class of TFC decision problem--for example, airstrike timing emission control planning, transit route planning, and so forth.

Prestructured models can be valuable decision aids for the TFC. By establishing an organized structure for analyzing certain decision situations, they decrease the likelihood that the commander will encounter a situation for which he is totally unprepared.

There are, however, certain risks associated with providing the TFC with prestructured models only. Because the models are applicable only to the specific situations for which they were designed, any decisions that are not covered by the models must necessarily be made without the benefit of decision aids. Furthermore, using prestructured models as decision aids can present difficulties even when the models are applied to the situations for

which they were designed. The commander may lack confidence that the prestructured model accurately reflects all of the unique considerations of his current situation. The commander's problem, then, is how to account for those aspects of a situation that may not be accurately reflected by the prestructured model. Fortunately structuring aids can reduce the risks and increase the usefulness of prestructured models.

1.2.2 Structuring Aids Complement Prestructured Models

Decision structuring aids complement prestructured models. They can be applied when prestructured models cannot, and they can be used in conjunction with prestructured models to produce integrated decision aids.

When the commander is confronted with an unstructured decision problem that is not easily dealt with using prestructured models or other standard methods of analysis, lack of time and resources usually prevents the development of anything more sophisticated than a qualitative or extremely simple quantitative analysis. The value of a decision structuring aid is that it expands the commander's capability to construct rapidly a formal quantitative model that, like a properly designed prestructured model, accurately accounts for all of the relevant considerations of his problem. Unlike prestructured models, however, a structuring aid enables the decision maker to construct a decision model in real time, after the characteristics of the situation have been identified.

The ability to structure a decision model in real time provides several important advantages. First, if the decision maker recognizes factors in the current situation that are not accounted for by the prestructured

models, those factors can be incorporated into the decision process by structuring a decision model that includes both the relevant prestructured models and those factors that are not included in the models. Second, the structuring process can be used to develop decision models for unanticipated situations for which no prestructured models have been supplied. Third, a decision structuring process allows the decision maker to participate directly in the construction of the decision model, thereby providing him with a better understanding of the model's asumptions and limitations. Because of this, the decision maker is likely to have confidence in the model and is more likely to use it effectively.

1.3 Decision Tree Structuring Format

The SRI decision structuring process is a computer-aided procedure for rapidly constructing and analyzing a decision model. The form of the decision model produced is a decision tree. The decision tree format was selected because it is a very general model form whose characteristics make it well suited for representing complex, sequential decisions that deal with uncertainty.

Figure 1 illustrates a decision tree model for a TFC planning decision taken from the ONRODA Scenario.* According to the scenario, a Blue TFC has been assigned the mission of neutralizing an enemy attack anticipated to be launched the next morning from ONRODA airfield against a Blue ally. The

*"The ONRODA Warfare Scenario [10]" describes the recent political and military history leading to a potential military conflict involving the hypothetical countries of Blue, Red, Grey. and Orange and the Island of ONRODA. This scenario has been designed to be used by contractors to test and to illustrate decision aids proposed within the ODA program.

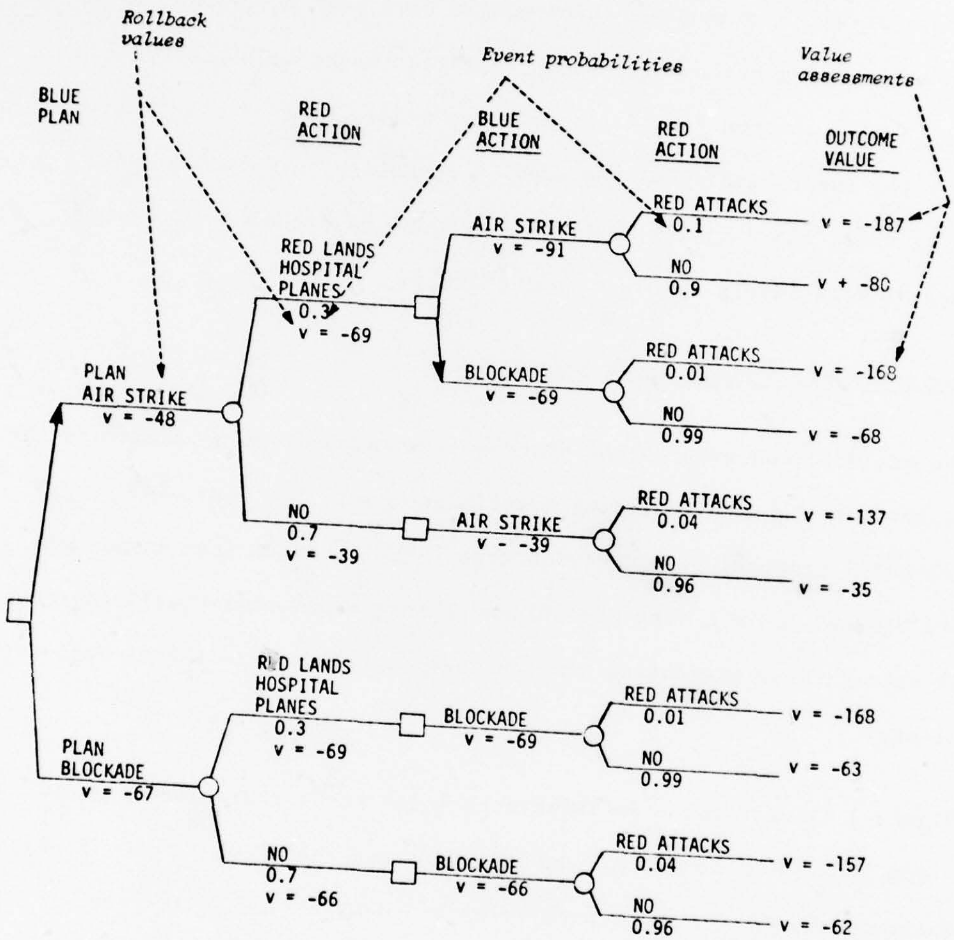


Figure 1 DECISION TREE REPRESENTING DECISION TAKEN FROM THE ONRODA SCENARIO

decision is whether the Blue TFC should plan to neutralize the ONRODA airfield with an airstrike or through a blockade. Important considerations for this decision, represented in the tree, include whether Red has civilian aircraft (such as hospital planes) on the airfield when the commander launches the airstrike, and whether Red will attack the task force in retaliation for the commander's actions.

In the decision tree format, decisions are represented by small squares, called decision nodes, with the various alternatives shown as lines emanating from each square. Uncertainties, such as enemy actions, are represented in the diagram by small circles, called chance nodes. The branches emanating from chance nodes represent the possible outcomes to each uncertain event.

The decision and chance nodes in a decision tree are arranged according to the sequence in which decisions must be made and in which outcomes of uncertain events will be revealed to the decision maker. Thus, each path leading from left to right through the tree represents a different possible sequence of decisions and events that might occur. As an example, suppose the commander chooses to plan an airstrike. The decision tree shows that reconnaissance will indicate whether Red has hospital planes on the airfield before the attack. If hospital planes are sighted, the commander can either launch his airstrike or revert to a blockade. Following whatever action is chosen, Red may or may not attack the task force.

A decision tree can be solved to obtain an optimal decision strategy. The first step is to provide the necessary numerical inputs-- probability assessments for the likelihood of the various outcomes to uncertain events,

and value assessments representing the relative desirability of each path through the tree.* Figure 1 shows example probabilities under the branches from chance nodes and sample values at the terminal points of the paths through the tree.

The next step is to compute expected values for each node in the tree. Expected values can be obtained using a roll-back procdure. The expected value at a chance node may be obtained by multiplying each terminal value by the probability along the branch leading to that value, and adding. Similarly if the rule is used that the decision maker will prefer the decision alternative with the highest expected value, the expected values for decision nodes can be determined.

Rolling expected values back through the decision tree in this manner enables a preferred decision strategy to be determined. The preferred decision strategy is the path through the tree that leads through alternatives with the highest (or least negative) expected values. For the example, the computed expected values indicate that the optimal initial decision is to plan an airstrike. The optimal decision strategy is to conduct an airstrike if no Red hospital planes are sighted and to revert to a blockade if Red hospital planes are sighted.

There are a number of advantages to selecting decision trees as the model for decision structuring. Most importantly, as mentioned earlier, the

*The values assigned to terminal nodes represent the desirability of the outcomes corresponding to each path through the tree. If a decision maker's risk aversion is also assessed, these values can be converted to utilities that account for attitude toward risk taking. Although we have chosen not to consider risk attitude in this report, all results can be easily extended to reflect risk aversion.

decision tree is a general model form that can be used to represent a wide class of decision situations. Another advantage is that a decision structuring process based on decision trees is compatible with the use of prestructured models. Prestructured models can be used for simplifying the generation of numerical inputs. Specifically, models can be developed to help estimate the probabilities associated with chance nodes, the outcomes associated with each path through a decision tree, and the values to be assigned to the terminal points of each path through the tree. For example if an airstrike outcome calculator were available for estimating the military outcomes under various strike patterns, it could be used in conjunction with the decision tree in Figure 1 to produce an integrated decision model.

Another major advantage to structuring a decision as a decision tree is that the methods for analyzing and solving decision trees are easily programmed. Thus, the same computer aid that helps construct the decision tree can be used to solve it. More importantly for a decision structuring process, a computer can be used to analyze a decision tree structure to identify how that structure should be expanded so as to improve its reliability.

1.4 Research Strategy and Current Status

This report is the third in a series of reports documenting SRI's research progress toward developing a computer-aided decision structuring process. Since the beginning of the research effort, an adaptive research strategy has been applied. As a result, the current direction and goals of the effort have been strongly influenced by earlier results and conclusions.

In recognition of the usefulness of decision trees for representing decision structure, initial research focused on formalizing the process by which experienced analysts construct decision tree models. Several experimental structuring sessions were recorded, transcribed, and then analyzed with the objective of identifying effective procedures for eliciting from a decision maker a decision tree representation of his situation. The major result was specification of the elemental steps performed as a decision analyst structures a decision model. The research, which is summarized in Reference [11], showed that the process of building a decision tree model could be represented as a sequential application of these elemental steps.

The next phase of the research was an evaluation of the degree to which a protocol for ordering the elemental structuring steps would aid the development of a decision model. The evaluation, which included several applications to current and past decision problems, indicated that the structuring protocol provided useful guidance for translating known decision factors into a mathematical model. However, the major limitation of the structuring protocol was that it failed to provide guidance for identifying the factors that should be included in the analysis. Two other important limitations of the standard method of analysis were also apparent. Application of decision analysis procedures frequently results in considerable effort being spent to model aspects of the decision problem that have little or no impact on the decision. Furthermore, the standard method of analysis provides little indication of which alternative being analyzed is best until the final stages of the analysis. This can be a serious drawback if, as occasionally happens, the user must terminate analyses prematurely.

As a result of these conclusions, research was directed toward developing a structuring process that both guides the modeling effort by helping the user to identify factors likely to impact the decision and supports a method of analysis that quickly produces a tentative solution, which may be improved through additional modeling. The resulting process is called the decision tree expansion algorithm because it is based on the concept of progressively expanding a decision tree--an initial decision tree model is analyzed to identify those areas of the model where adding more detail is most likely to indicate an improved decision. The decision tree expansion algorithm and a preliminary computer implementation are described in Reference [12].

Experimental applications of the decision tree expansion algorithm showed that two major improvements would be needed to increase its usefulness as a decision aid. First, the computer implementation would have to be made more convenient and flexible by both streamlining the algorithm and providing graphics for output display. Second, procedures were needed to help the user develop the preliminary decision tree used to initiate the tree expansion algorithm. The most recent stage of the research has been directed at these two areas. Consequently, although this report summarizes the current status of the SRI decision structuring process, the major emphasis is on refinements in the design of the expansion algorithm that improve its convenience and flexibility, improved graphics design for the user interface, and the preliminary structuring process that has been designed to help the user develop the initial decision tree required to enter the expansion algorithm.

The research strategy for completing the development of the computer-assisted structuring process calls for three major activities. The first and most obvious requirement is to complete the computer implementation. The tasks remaining here are to program the computer aids for carrying out the preliminary structuring procedures that produce the initial decision tree model, to integrate this program with the program for decision tree expansion, and to complete graphics development for the integrated program. Once the computer aids for the structuring process are fully operational, the second remaining research activity is to evaluate and modify aid operation through a program of developmental testing and redesign. Previous tests of the structuring process have not directly involved the computer. Developmental testing envisioned here would use the computer aid to structure several sample decision problems with the intent of assessing the degree to which the aid facilitates application of the structuring process. We expect testing in this way to suggest a number of modifications that will be made at this point in the research program. The third and final remaining research activity is to conduct a thorough and independent evaluation of the aid on the ODAP test-bed facilities. At this stage of the effort, the role of the designers is expected to be primarily advisory, as experimental testing is likely to be conducted by a team of specialists in experimental design and evaluation.

2. OVERVIEW OF THE DECISION STRUCTURING AID

This section presents an overview of the structuring process and its associated computer aids. A more detailed description of the process is presented in Sections 3 and 4.

2.1 Major Components and Important Characteristics

Figure 2 illustrates the major components of the SRI decision structuring process. The process is carried out in two distinct phases. The first phase, called the preliminary structuring phase, is designed to develop a simple decision tree that represents only those factors and relationships immediately apparent to the decision maker. This initial decision tree is referred to as the preliminary decision model. The primary aid for the preliminary structuring phase is an interactive computer program for systematic inquiry and decision tree generation.

Because the first simple model that is constructed often overlooks factors, the preliminary structuring phase is followed by a second phase, called the expansion phase. The purpose of the expansion phase is to identify and bring into the preliminary decision model additional important factors. The primary aid for the expansion phase is an interactive computer program for decision tree expansion and analysis.

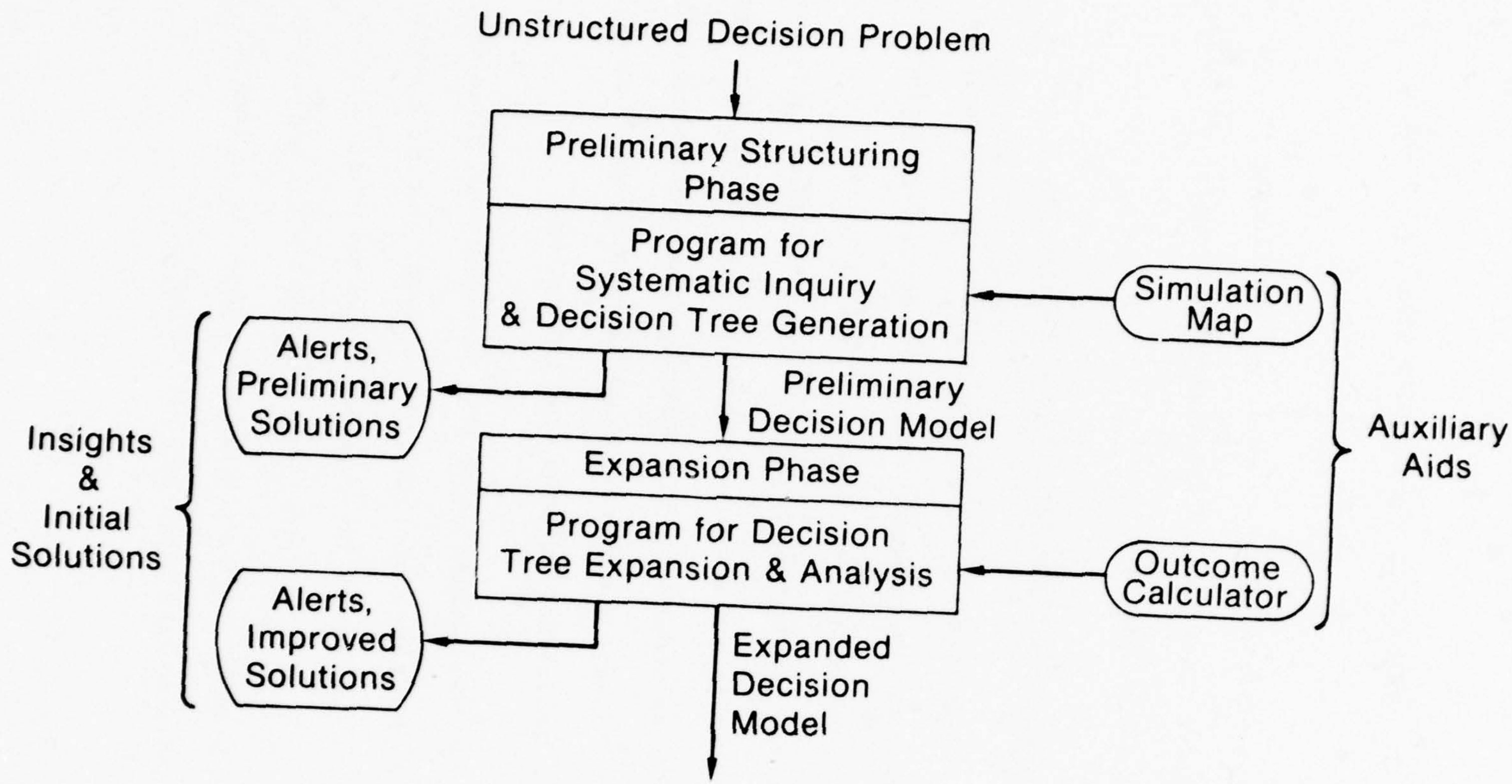


Figure 2 MAJOR COMPONENTS OF THE STRUCTURING PROCESS

As will become clear in Section 4, application of the structuring process requires the user to supply quantitative estimates for the outcomes to each decision alternative under various assumptions. Providing the large number of outcome estimates can become burdensome if calculated by hand; so, the structuring process is designed to be used with prestructured models for estimating military outcomes. In the preliminary structuring phase, a simulation map is used as an auxiliary aid for estimating decision outcomes. In the expansion phase, an analogous but more sophisticated version of the same aid is an outcome calculator. The structuring process may be used without prestructured models for estimating outcomes; however, its use in this mode will be more time-consuming.

The ultimate output of the structuring process is a fully structured decision model along with the insights and solutions produced through an analysis of that model. Interim outputs include a series of preliminary models and the solutions to these models. Since the decision model is improved as it is expanded to include more and more of the relevant decision factors, the preliminary solutions are improved as the process is carried out. Having a tentative solution always available is valuable, because the structuring process may be profitably terminated at any point. The most recent model and its solution provide an approximation to the optimal decision strategy that would be produced if the structuring process were carried out to completion. In practice, the decision maker will terminate the structuring process whenever he perceives that the improvements gained from further structuring and analysis do not warrant additional investments of his time.

Additional features that enhance the value of the structuring process as a decision aid include the following:

- The applicability of the aid is exceedingly general. It may be used to structure virtually any dynamic, uncertain, decision problem with single or multiple objectives. There is no limit to the number of alternatives or uncertain decision factors that can be included in the decision structure.

- The aid does not require common over-simplifications concerning the probabilistic independence of uncertainties or the shapes of their probability distributions.

- The aid tests new factors introduced during the expansion phase for relevance to the decision at hand, thereby avoiding time-consuming modeling effort when it has no impact on the decision.

- The algorithm provides a method for identifying events that are of critical concern to the TFC. Such events could be used as triggers (for example, setting alerts in the DAISY System).

- Application of the aid produces graphical output that summarizes decision structure and documents the decision-making process.

2.2 Test Facility Configuration and Graphical Capabilities

The interactive computer programs for applying the decision structuring process have been designed and are partially implemented on the ODA test-bed facility. Figure 3 shows the configuration. Three video screens may be used

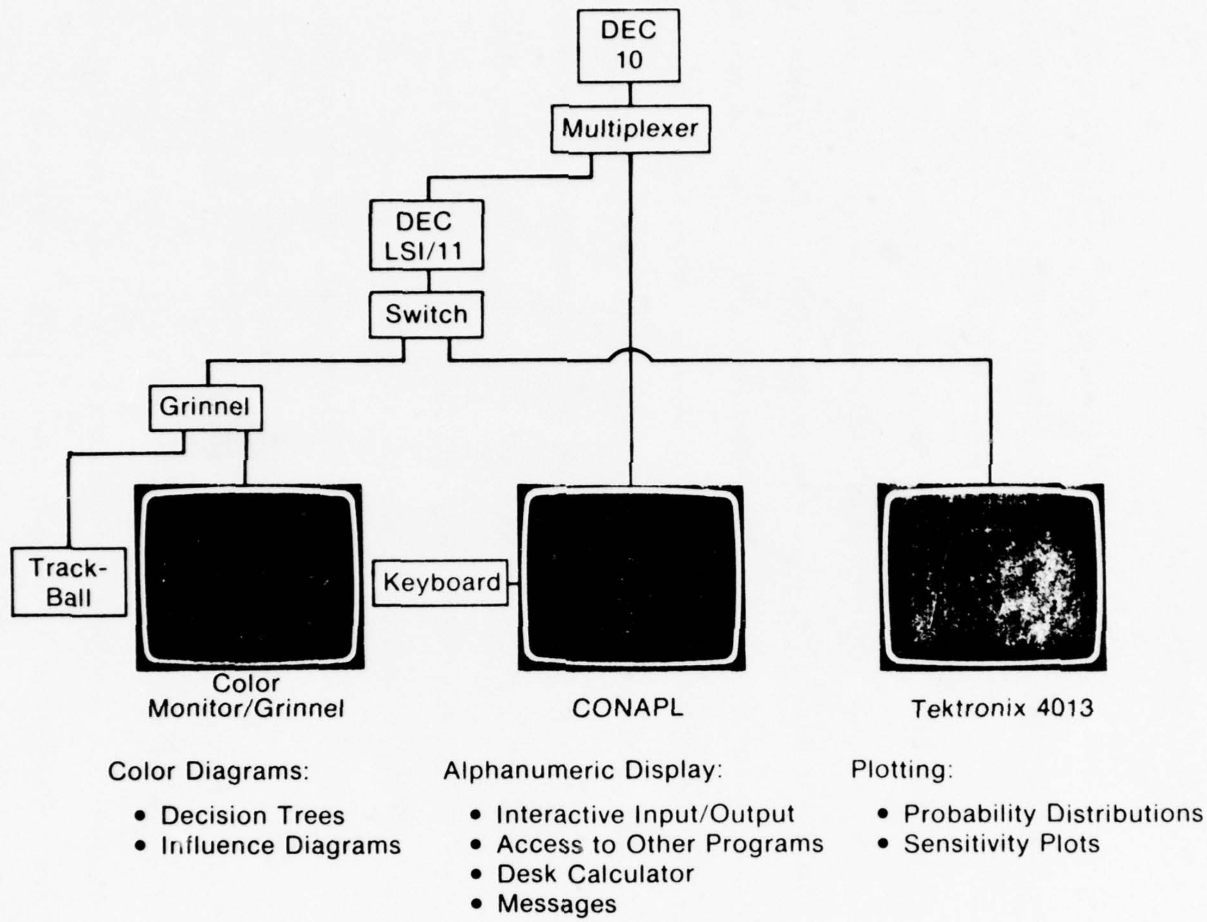


Figure 3 DEVICES USED IN TEST-BED IMPLEMENTATION

simultaneously for output: a color monitor tied to a Grinnel display system for representing decision trees and influence diagrams, a CONAPL graphics terminal for alphanumeric input and output, and a Tektronix 4013 for plotting probability distributions and sensitivity plots. Input devices consist of a keyboard and track ball.

Figures 4 through 6 give examples of the display formats designed for the various outputs produced during application of the structuring process. Figure 4 shows the use of the CONAPL graphics as the primary input/output interface. Here, the computer is requesting outcome estimates required for the expansion phase. All computer generated prompts and questions, as well as user alphanumeric input, are displayed on the CONAPL. Figure 5 is a plot of a probability distribution that the computer has fitted to the user's high, best, and low estimates for aircraft losses. Probability distributions and sensitivity plots are displayed on the Tektronix. Figure 6 illustrates the manner in which a decision tree is displayed on the Grinnel monitor. Although not visible in the black and white illustration, decision trees and other model representations are displayed using color. For example, when a decision tree is displayed, the decision strategy with the highest expected value is denoted with a blue arrow and the path through the tree recommended for additional structuring is highlighted in red. Most of the alphanumeric and graphical displays provided by the aid are intended for use by a staff analyst and other staff officers who provide inputs to the system. Some displays, however, are designed to be viewed by the commander as well. These include displays showing sensitivities, preference relationships, and recommended decision strategies.

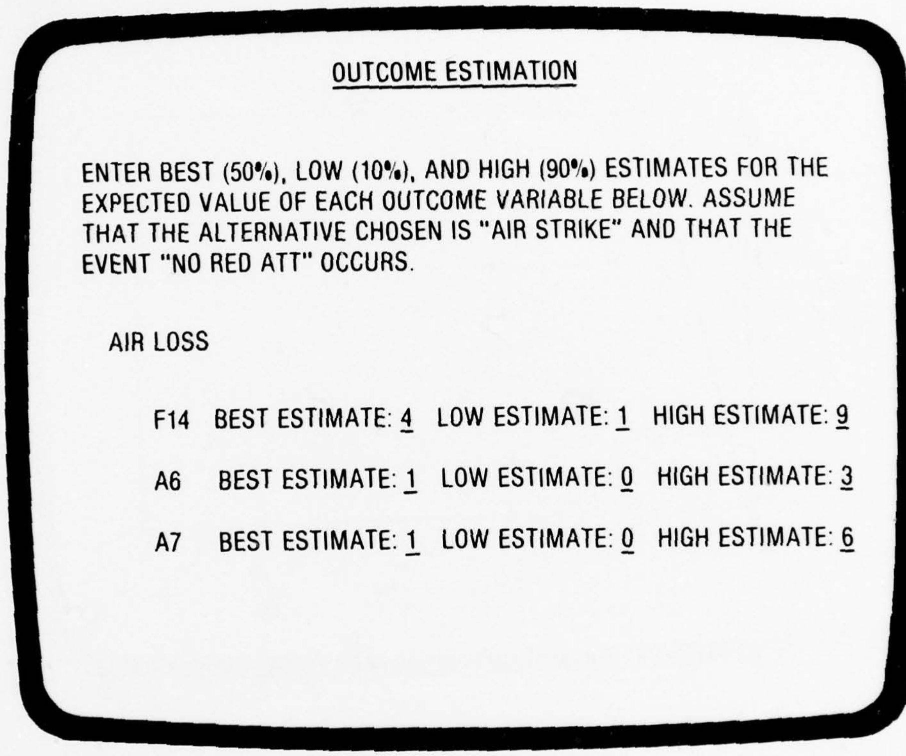


Figure 4 TYPICAL ALPHANUMERIC DISPLAY USED IN STRUCTURING PROCESS

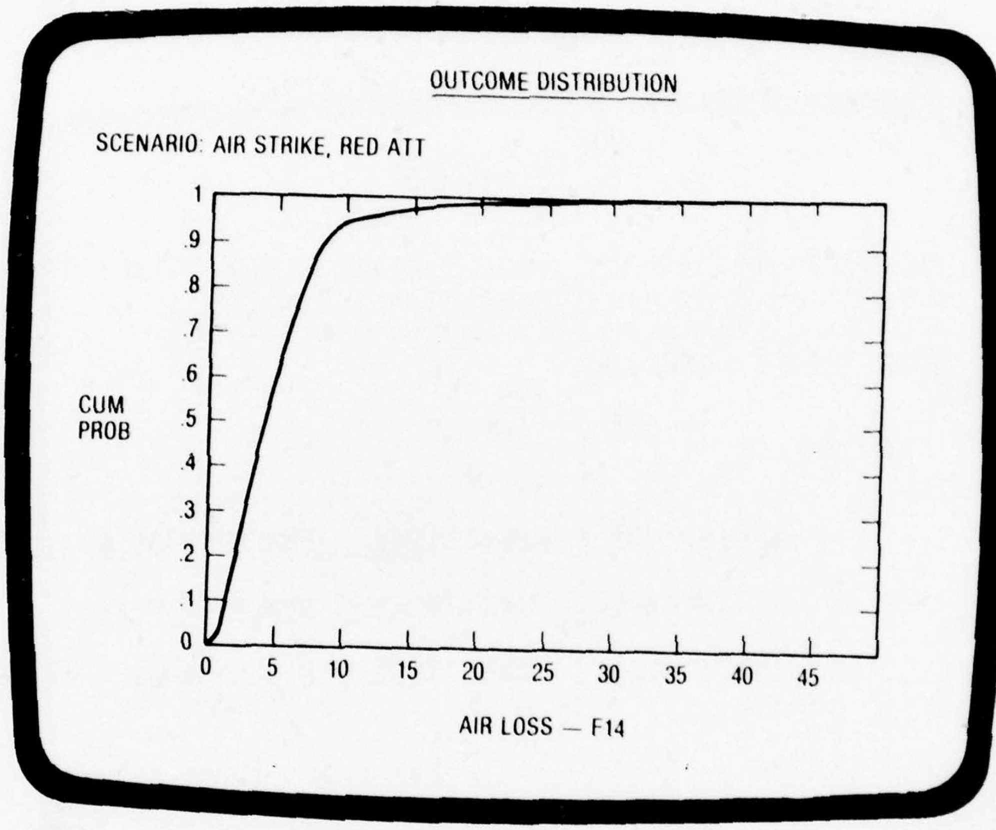


Figure 5 DISPLAY SHOWING PROBABILITY DISTRIBUTION PLOT

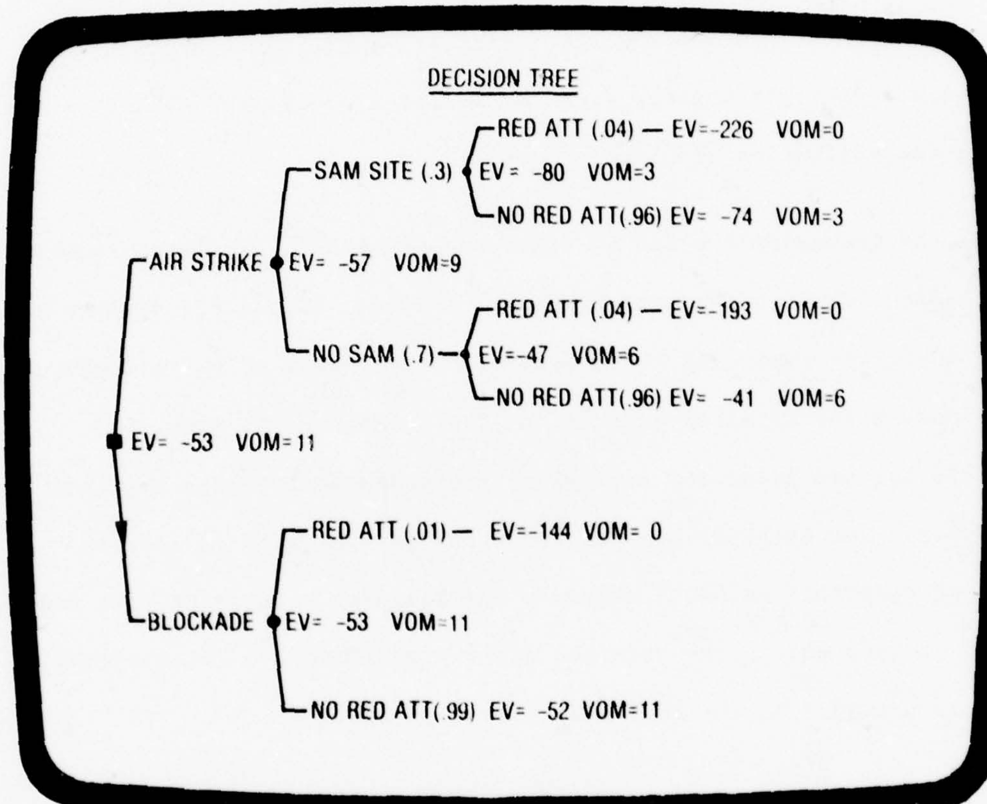


Figure 6 DECISION TREE DISPLAY

2.3 Implementation as a Man-Machine System

Figure 7 illustrates how the decision structuring process is designed to be implemented as a man-machine system. The commander works with a member of his staff, henceforth referred to as the staff analyst, to identify and organize the relevant factors of his decision into a decision model. The computer assists the staff analyst by acting as a prompting system, as a medium for constructing the decision model, and as a tool for assisting the evaluation of alternatives.

From the commander's point of view, the structuring activity consists of a well-directed dialogue with his staff analyst. The staff analyst asks specific questions regarding the commander's assessment of the situation and suggests issues for detailed discussion. The commander, in turn, is responsible for providing (or verifying) the judgmental inputs required for the analysis. The computer prompts the staff analyst with an orderly sequence of questions and data requests for building a decision tree model. The staff analyst enters the required data, translating or interpreting information provided by the commander, if necessary.

As the decision model is constructed, the computer analyzes the model to identify sensitive model areas that should be refined or expanded. Normally, the commander will not operate the computer directly. However, depending on the commander's wishes, the staff analyst may supply the commander with a summary or detailed "running report" of analysis results.

Elements of the decision model that are not specific to the unique characteristics of the decision at hand are provided as inputs to the

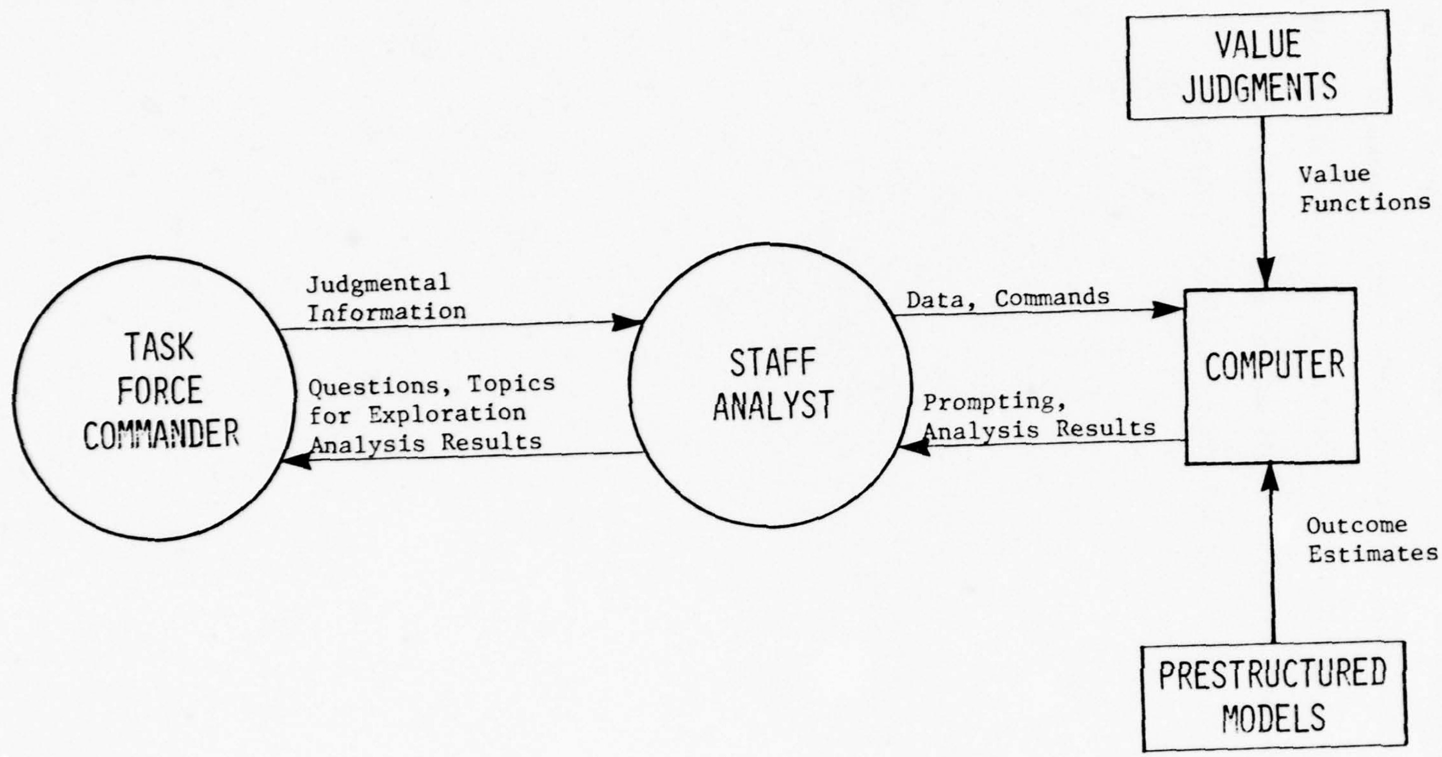


Figure 7 IMPLEMENTATION OF THE STRUCTURING PROCESS AS A MAN-MACHINE SYSTEM

computer. One major input required is a value model that describes the relative importance or value of the attributes of military outcomes-- for example, the willingness to trade off own force losses of various types for accomplishment of mission objectives. Other major inputs are prestructured models for estimating military outcomes. As mentioned above, use of prestructured outcome calculators allows the structuring process to be carried out in the most rapid and efficient manner possible.

3. THE PRELIMINARY STRUCTURING PHASE

As discussed briefly in Section 2, the SRI decision structuring process consists of a preliminary structuring phase and an expansion phase. The preliminary structuring phase is designed to produce a simple decision tree model representing only the most important factors of the decision as initially perceived by the decision maker. Although the preliminary structuring phase precedes the expansion phase in a typical application, the historical development of the two phases proceeded in the opposite order.

The decision tree expansion algorithm underlying the current expansion phase was originally viewed as the basis for the entire structuring process. The original concept of operation was that a user would define a "zero'th order tree" consisting only of a single decision node, with branches eminating from that node representing each of the recognized alternatives. The expansion algorithm would then be used to expand the tree, adding one factor at a time, until a decision tree was obtained that contained all of the major uncertainties and down-stream decisions required to represent accurately the decision situation.

Early, informal applications of the expansion algorithm pointed out that, although this approach worked, it was an inefficient way to structure those decision factors already known to the decision maker. A procedure was needed for quickly generating an initial decision tree that contained those

decision factors and relationships that are immediately apparent. Consequently, research was initiated to develop a preliminary structuring process.

3.1 Concept of Operation

The preliminary structuring process is an elicitation procedure designed to clarify the commander's understanding of his decision problem and to assess the information necessary to construct a decision tree representing the most important of the readily apparent decision factors. The elicitation is conducted through a series of questions grouped according to the specific function is being carried out in the structuring process. Each function accomplishes a necessary step in the construction of a decision tree. For example, one structuring function is designed to elicit the set of feasible alternative courses of action available to the commander. Another function is designed to specify a set of uncertainties that must be accounted for in the selection of a decision strategy.

The number and content of the specific questions composing each function are adaptive and depend on the answers given to previous questions. In addition, the order in which the questions are posed and, more generally, the overall approach are designed to achieve four important objectives:

1. Structuring activity initially focuses on improving the understanding of decision objectives and then on refining an initially preferred alternative. The intent is to begin producing results directly applicable to the formation of a decision strategy as quickly as possible.

2. Input requirements are kept to a minimum. The process is designed primarily to organize and simplify the application of human problem-solving skills rather than to replace those skills with machine processing. This contributes to relatively speedy generation of insights.

3. The steps and specific questions asked are designed to encourage a more objective understanding of the situation by countering several recognized decision-making errors and biases.

4. The output of the process is a decision tree in a format consistent with the requirements of the expansion phase.

Figure 8 is a flowchart showing the specific preliminary structuring functions and the order in which they are executed. The purpose of each of the structuring functions as well as motivation for the design are summarized in the paragraphs below. The detailed steps and queries for carrying out each function are described in Subsection 3.3.

3.1.1 Objective and Outcome Variable Identification

The first function to be executed in the preliminary structuring process is objective and outcome variable identification. The principal outputs are a list of decision objectives and a list of associated outcome variables.

The initial steps in this function elicit a complete set of objectives for the decision. The elicitation is designed to identify not only physical but any political, economic, or other military decision objectives as well.

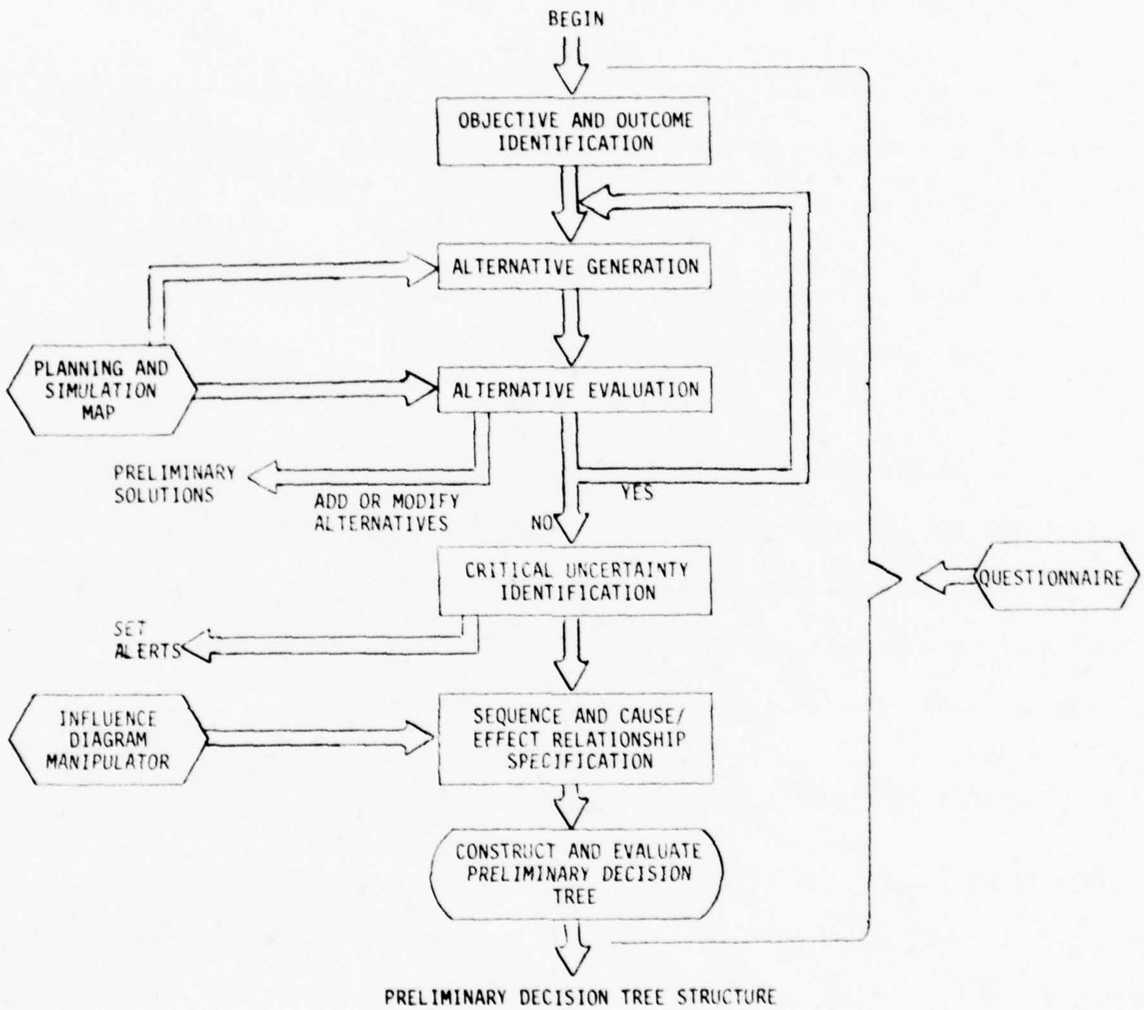


Figure 8 FLOWCHART OF PRELIMINARY STRUCTURING ALGORITHM SHOWING PRELIMINARY STRUCTURING FUNCTIONS: , COMPUTER PROCESSING: , AND KEY DECISION AIDS: .

For example, one objective for a naval mission will often be to achieve some physical objective, such as gaining control of a geographical area. Another objective will be to minimize own force losses. Still another might be to avoid any action that might provoke another nation to enter the conflict as an ally of the enemy.

Once a complete list of objectives is identified, the next step is to create a list of outcome variables. Outcome variables are measures for assessing the degree to which the decision outcome achieves each objective. The outcome variables should be quantifiable-- quantities whose values may be expressed by numbers. For example, outcome variables for the objective "minimize own force loses" might be the number and type of own force units that are destroyed or sustain significant damage as a result of the decision outcome.

Research suggests that a structuring process designed to focus initially on objectives rather than alternatives has some advantages. A common decision-making error is to define the decision problem too narrowly by confusing a specific alternative with an objective. For example, suppose a TFC finds himself in a situation where he must protect a group of civilians on a small island who are threatened by an anticipated invasion. The commander may perceive his decision problem as a choice between strategies for preventing the invasion. By stepping back from his problem and recognizing that his objective is to protect civilians, he is less likely to overlook other viable alternatives, such as evacuating the civilians from the island. Focusing first on the objectives of the decision

tends to clarify the decision maker's understanding of the situation and promotes openmindedness in the generation of alternatives.

3.1.2 Alternative Identification

The second function in the preliminary structuring process is elicitation of decision alternatives. This is obviously a crucial step because no amount of analysis can lead to the selection of a best alternative if that alternative has not been included in the decision structure.

Unfortunately little is known about the creative process of defining new alternatives. Limited research suggests that the creation of new alternatives can be encouraged by involving several individuals with different points of view in the decision-making process, by applying brainstorming techniques, and by using morphological methods. Few of these techniques, however, have been developed to the point that they can be incorporated into an automated decision aid.

The alternative identification function in the preliminary structuring process makes use of two techniques for encouraging the generation of a complete list of alternatives. The first is the formalization of a "devil's advocate" role for challenging each decision alternative. This is discussed below in the description of the scenario generation function. The second technique is to supply the commander with a list of generic alternatives. The list of generic alternatives used in this function is derived from a study of historic decision situations conducted by CACI, Inc. [13]. By considering each generic decision type in the list, the commander can decrease the likelihood that an effective alternative has been overlooked.

The output of the alternative generation function is a list of feasible courses of action.

3.1.3 Alternative Evaluation

The alternative evaluation function is designed to produce an estimate of the likely outcomes and risks associated with each alternative course of action. Scenario generation is used as the basis for the evaluation. Because of their training and experience, TFC's tend to think in terms of events and reactions to events. Thus, scenarios provide a familiar, concise, and consistent framework for organizing the commander's thoughts.

Steps in the function are designed to permit the TFC and the staff to generate scenarios that describe the likely outcomes of a given course of action as well as scenarios that make the course of action look very bad. Generating a scenario that makes a course of action look very bad accomplishes two things. First, it counteracts a general error or bias in decision making sometimes referred to as "mindguards". Mindguards refers to the observed tendency of decision-makers to limit or distort their world views so as to produce a less threatening perception of difficult situations. Typical examples of such behavior are enemy stereotyping and rationalization. The result of these biases is usually a failure to consider adequately the risks or negative aspects of a prefered course of action. By formalizing a devil's advocate evaluation of each alternative, a deliberate attempt is made to counteract the tendency to create mindguards. A second value to generating a scenario that makes each alternative look very bad is that consideration of possible risks challenges the commander and his staff to come up with modifications to the course of action or new

alternatives that achieve the same benefits without the risks. An earlier phase of the SRI research effort indicated that challenging a decision maker by pointing out specific disadvantages or risks associated with a prefered action is an effective way to encourage the creation of new alternatives. For this reason, as shown in Figure 8, the output of the alternative evaluation function can lead back into the alternative generation function.

3.1.4 Critical Uncertainty Identification

The critical uncertainty identification function is designed to produce a list of crucial state variables representing those uncertainties whose probabilities must be explicitly accounted for in the decision model. The approach to generating the list is to compare the most likely and worst scenarios for each retained alternative. The difference in the scenarios represents uncertain events that influence the relative preference for the alternatives.

Once the uncertainties that influence the decision are identified, each uncertainty is described by a state variable defined so that the possible values for the variable correspond to the possible outcomes of the uncertain event. For example, if the difference between a likely and worst possible scenario for a given alternative is the prevailing weather condition assumed, weather would be listed as a critical uncertainty. A corresponding state variable could be defined by specifying a variable called weather that could take one of two values: good or bad. For simplicity, all uncertain variables defined in this structuring function are assumed to be discrete.

3.1.5 Sequence and Cause/Effect Relationship Specification

The sequence and cause/effect relationship specification function is designed to produce a summary of the relationships among decision variables, uncertain state variables, and outcome variables. This is accomplished by using influence diagrams. Influence diagrams are diagrams whose structure summarizes the probabilistic dependencies among uncertainties and specifies the sequence in which decisions must be made and information becomes available. The specific steps of this function that permit the construction of an influence diagram are illustrated in Section 3.3.

3.1.6 Preliminary Decision Tree Construction

The final function in the preliminary structuring phase is to construct and evaluate a preliminary decision tree. Steps in this function convert the influence diagram created in the previous function into a decision tree structure. The tree structure is the major output of the preliminary structuring phase and the major input to the expansion phase. The required numerical inputs for the tree--value assignments and probabilities-- are elicited and the tree is solved in the expansion phase.

3.2 Aids for Preliminary Structuring

The primary computer aid for the preliminary structuring phase is an interactive program for systematic inquiry and decision tree construction. An important associate aid used to support outcome estimation and detailed planning is a simulation map.

3.2.1 Interactive Program for Systematic Inquiry and Decision Tree Construction

The program for inquiry and decision tree construction consists of two main elements: an automated questionnaire that guides the user through the six preliminary structuring functions and an influence diagram manipulator used to simplify the construction of a decision tree. Both elements have been designed, but neither has been implemented on the ODA Program test bed. The influence diagram manipulator, however, has been partially implemented on computers at SRI International.

Figure 9 illustrates the use of the graphics terminal as an automated questionnaire. The first few questions that step the user through the objective identification function are shown together with sample user responses. The complete set of questions for the automated questionnaire is illustrated in Subsection 3.3.

The primary motivation for automating the questionnaire is to permit automatic adjustment of prompting detail and branching. Three levels of prompting detail are available, ranging from a detailed request with explanation for each input required to abbreviated prompting. Branching provides a way to tailor the questionnaire to the user's needs in a particular decision situation. As an example, proper execution of the objective and outcome variable identification function should generate a small list of separable outcome measures. If too many outcome measures are defined, later input requirements are increased. Furthermore, some of the measures are likely to be redundant or of only minor importance. The

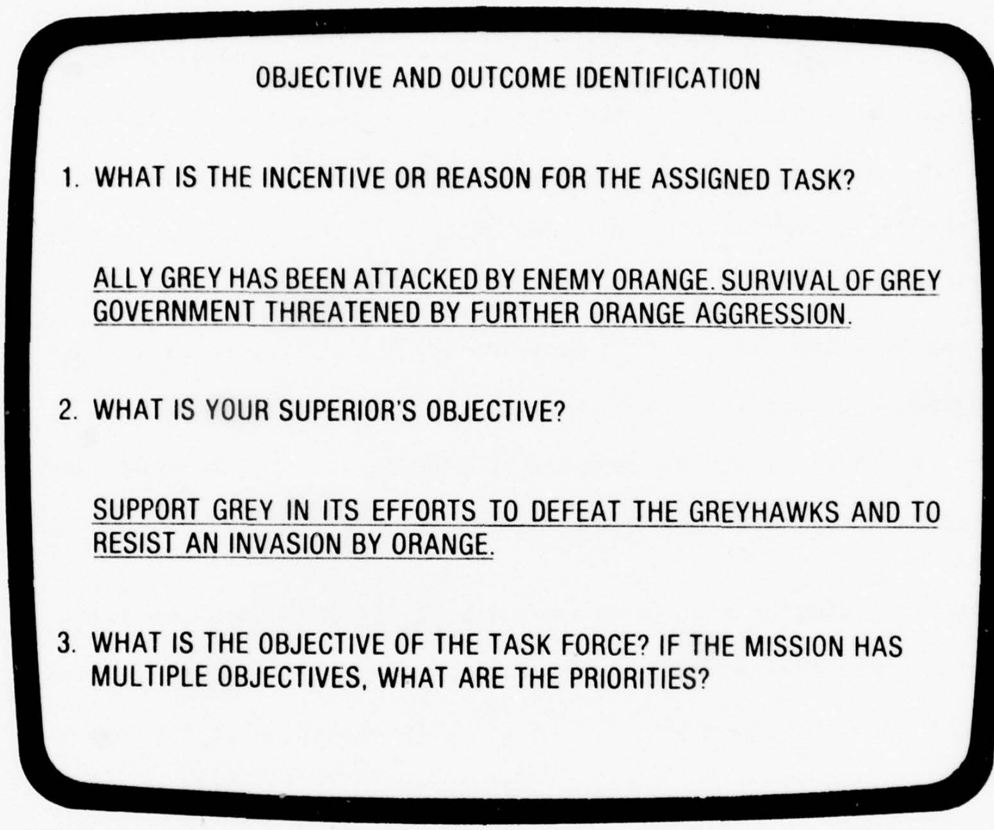


Figure 9 AUTOMATED QUESTIONNAIRE

computer, therefore, counts the number of outcome measures that have been identified. If there are less than five, no additional action is taken; if there are more than five, a series of questions is presented to identify and eliminate less significant measures and to combine outcome measures that are redundant.

The influence diagram manipulator allows the user to construct, modify, and analyze influence diagrams. Influence diagrams are graphical devices for describing the relationships among the variables in a decision. They are a more general representation than decision trees and, yet, are easily interpreted by individuals at all levels of technical proficiency. Methods for converting influence diagrams to decision trees can be automated. Hence, influence diagrams provide a useful device for simplifying the construction of a decision tree. A detailed description of the theory and use of influence diagrams is contained in Reference [14].

The influence diagram manipulator permits the user to constuct and display an influence diagram with the support of the computer. It is used along with the automated questionnaire to simplify execution of the sequence and cause/effect specification function and the decision tree construction function. Figure 10 illustrates the use of the influence diagram manipulator in conjunction with a question from the sequence and cause/effect specification function. Boxes with right-angled corners in the influence diagram represent decisions. Boxes with rounded corners are chance nodes and represent critical uncertainties. An arrow from a chance node or a decision node to another chance node indicates that the probabilities associated with the second uncertainty depend on the outcome

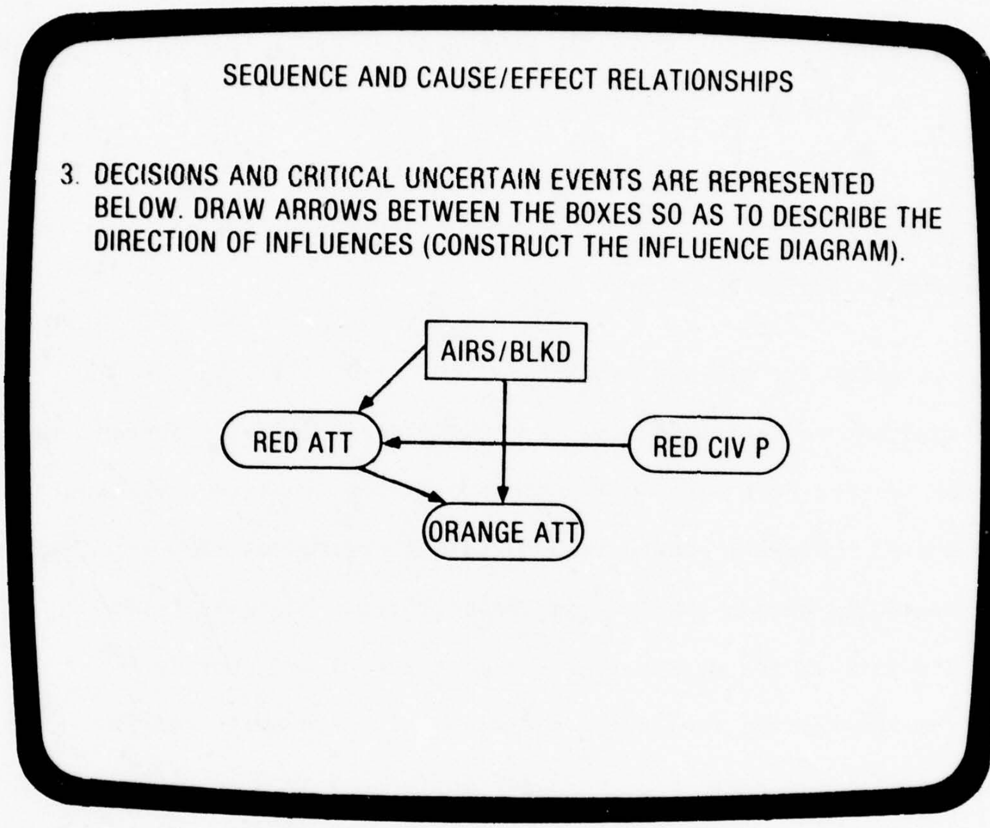


Figure 10 USE OF INFLUENCE DIAGRAM MANIPULATOR IN AUTOMATED QUESTIONNAIRE

of the first uncertainty or the decision taken. An arrow from a chance node or a decision node to another decision node indicates that the second decision is made with knowledge of the first uncertain outcome or decision.

3.2.2 Simulation Map

The simulation map is a manual war game for simulating the force movements and engagement outcomes resulting from a given course of action. The game concept is similar to a simulation game recently developed at the Naval War College [15] and other commercially available war games (see, for example, Reference [16]).

Figure 11 shows the playing surface for the simulation map used in sample applications to decisions from the ONRODA Scenario. The surface is roughly three by five feet with geographic boundaries drawn to scale and covered by a grid. Playing pieces are provided to represent each force unit that may potentially become involved in the conflict. The game rules specify constraints on the movement of the game pieces and provide guidelines for determining the likely positions of force units and the losses resulting from a given own course of action and assumed enemy response.

Figure 12 shows several of the playing pieces used in sample applications. Each playing piece is a small cardboard square coded to represent the movement capabilities and offensive and defensive strengths of a particular force unit. Uncertainty in detection and kill is explicitly represented in estimated outcomes. The various force strength numbers on each playing piece are selected to reflect appropriate exchange ratios.

SIMULATION MAP

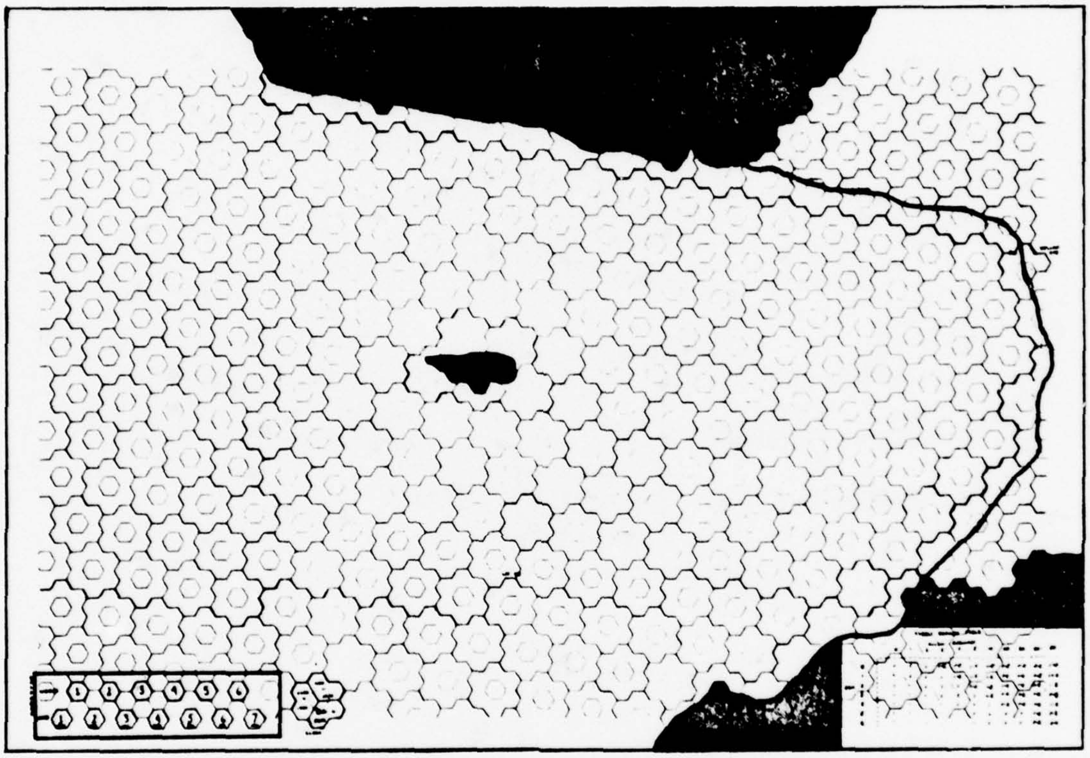


Figure 11 SIMULATION MAP

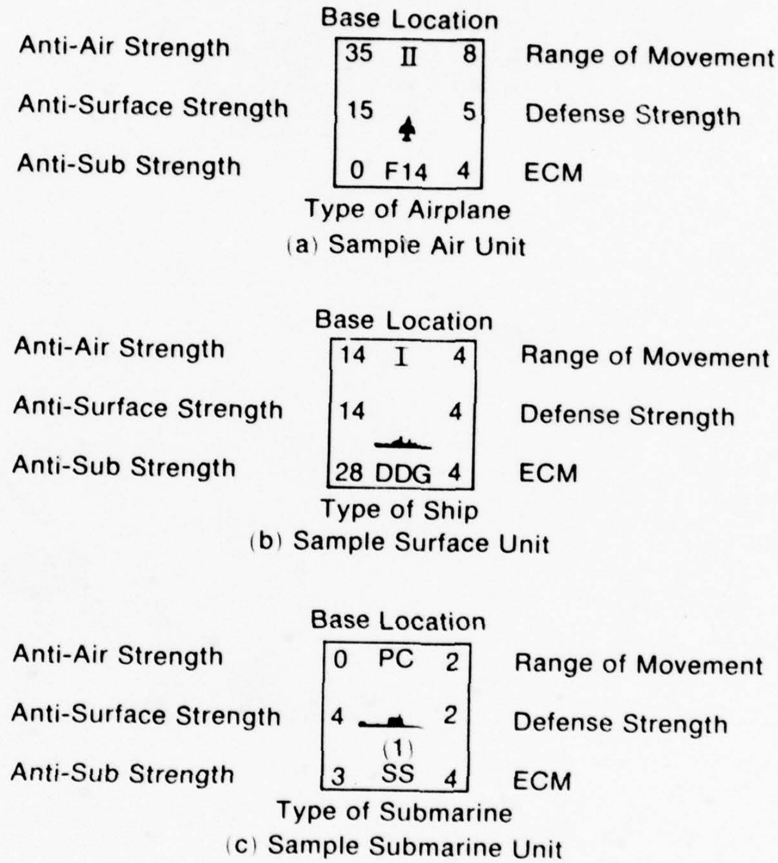


Figure 12 TYPICAL SIMULATION PLAYING PIECES

(Matching the offensive and defensive strengths of opposing units produces engagement outcome probabilities that are consistent with published exchange ratios.) A method of table look up is used to obtain probabilities of possible outcomes for each engagement.

The simulation map is used in the alternative evaluation function to help estimate decision outcomes. The user moves the game pieces corresponding to his forces to reflect a given course of action. He then moves enemy pieces according to likely enemy responses and observes the resulting engagement outcomes. In practice, the user will make small adjustments to each proposed strategy so that, when he plays it out on the simulation map, he minimizes his likely losses for a given level of effectiveness.

The simulation map provides sufficient detail to model realistically the complex interactions of an engagement between opposing naval forces: yet, it is flexible enough to accommodate several different scenarios without extensive redesign. Although the simulation map is currently implemented as a manual system, it could obviously be fully automated.

3.3 Sample Application of the Preliminary Structuring Aid

The detailed questions and method of application for the preliminary structuring functions are best illustrated through the results of a sample application. Exhibit 1 illustrates the preliminary structuring questions generated and user responses obtained during an application to the planning decision in the ONRODA Scenario. For clarification, the dialogue has been outlined and labeled to show at each point which preliminary structuring function is being executed. Machine-generated questions and prompts are shown in bold-face type. User responses are shown in italics.

EXHIBIT 1: SAMPLE APPLICATION--PRELIMINARY STRUCTURING PHASE

A. Objectives and Outcome Identification

1. What is the incentive or reason for the assigned task?

Ally Grey has been attacked by enemy Orange. Survival of Grey government threatened by further Orange aggression.

2. What is your superior's objective?

Support Grey in its efforts to defeat the Greyhawks and to resist an invasion by Orange.

3. What is the objective of the task force? If the mission has multiple objectives, what are the priorities?

In order of importance:
1. Neutralize the Orange air forces on ONRODA Island.
2. Avoid direct involvement in conflict by Red.
3. Deliver military supplies to Grey.

4. What specific measures could be used to indicate the degree of mission success?

Number of sorties enemy can launch against Grey following Blue action.

Probability of Blue/Red war.

[If the user indicates he is having trouble with this question (e.g., if he types *HELP*), the program moves immediately to item A5. After a response is given, question A4 reappears in the modified form:

4'. Are there any additional outcome measures that are specific to this mission? If so, please list them.]

5. The following are outcome measures that may be important for judging the success of naval task force missions. Check any additional measures that, if not explicitly considered, might result in the choice of a poor alternative.

___ time required to complete mission
xxx own equipment damaged or destroyed
___ enemy equipment damaged or destroyed
___ position or capabilities of forces at conclusion or engagement
___ political consequences

---

*Three levels of detail are available in the elicitation format. Level 1 (most detail) is shown. Level 2 consists of only underlined questions. Level 3 consists of only double underlined questions.

6. Your answers indicate the following preliminary hierarchy of objectives:

Superior's objectives:

Support Grey in its efforts to defeat the Grey-hawks and to resist an invasion by Orange.

Task force objectives:

A. Neutralize the Orange air forces on ONRODA Island

B. Avoid direct involvement in conflict by Red

C. Deliver military supplies to Grey

Outcome measures:

1. Number of sorties enemy can launch against Grey following Blue action

2. Probability of Blue/Red war

3. Own equipment damaged or destroyed

Are all aspects of the task force objectives accounted for by the outcome measures? If not, please identify those aspects that are not currently included.

CR

[If the user indicated instead that something has been omitted, the following version of question A4 is repeated:

6a. (displayed only if response to item 6 is positive) What specific measures could be used to indicate the degree to which this objective is achieved?

Any newly identified outcome measures are added to the displayed list.]

[If more than a total of 5 outcome measures are listed, there is a good chance that some are redundant and the following questions are asked:

6a'. (displayed only if the number of outcome measures is greater than 5) Consider each outcome measure in turn. If you ignored this aspect of the outcome, could it possibly lead you to an incorrect decision?

Outcome Measure	Important to Decision Yes	No
1. Number of sorties enemy can launch against Grey following Blue action	xxx	
2. Probability of Blue/Red war	xxx	
3. Own equipment damaged or destroyed	xxx	
4. Enemy aircraft destroyed	xxx	
5. Tons of military supplies to Grey		xxx

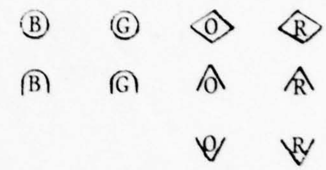
Table 1

KEY TO SYMBOLS USED IN DISPLAYS

Blue, Grey, Orange, Red ships:

Blue, Grey, Orange, Red aircraft:

Orange, Red submarines:



6b'. (displayed only if the number of outcome measures is greater than 5) Are any of the outcome measures redundant? Two outcome measures are redundant if knowing the level of one essentially tells you the level of the other.

Yes

Which outcome measures are redundant (identify by number).

1, 4

These outcome measures will be combined. What do you wish to call the result?

Enemy sortie capability]

B. Alternative Generation

[Alternative generation and alternative evaluation are accomplished with the aid of the simulation map (described in Subsection 3.1.2). Displays 1 through 14 included in this exhibit are rough sketches showing the approximate configuration of the game pieces and the movement of game pieces at various stages of preliminary structuring process. The key defining display symbols is given in Table 1. Display 1 shows the configuration of the simulation map at the initiation of this function.]

1. Prepare a list of tentative own courses of action which, if successful, will accomplish the mission.

--*Airstrike of ONRODA followed with Orange/ONRODA blockade*

--*Destroy ONRODA airfield with naval gunfire*

--*Amphibious landing*

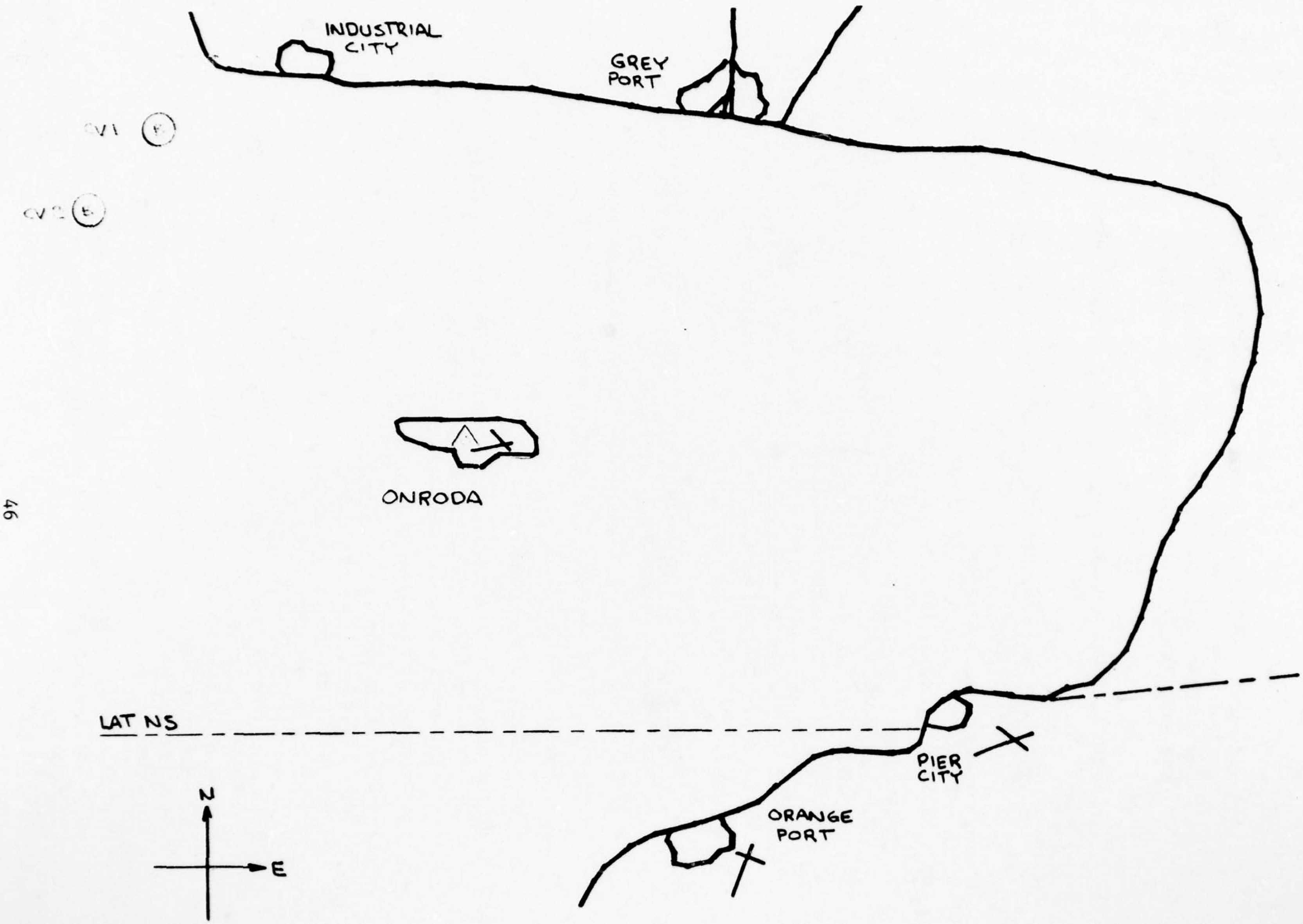
--*Grey/ONRODA air blockade*

[If the user indicates that he is having difficulty compiling a list of alternatives (e.g., if he types *HELP*), the following is displayed and item B1 is then repeated:

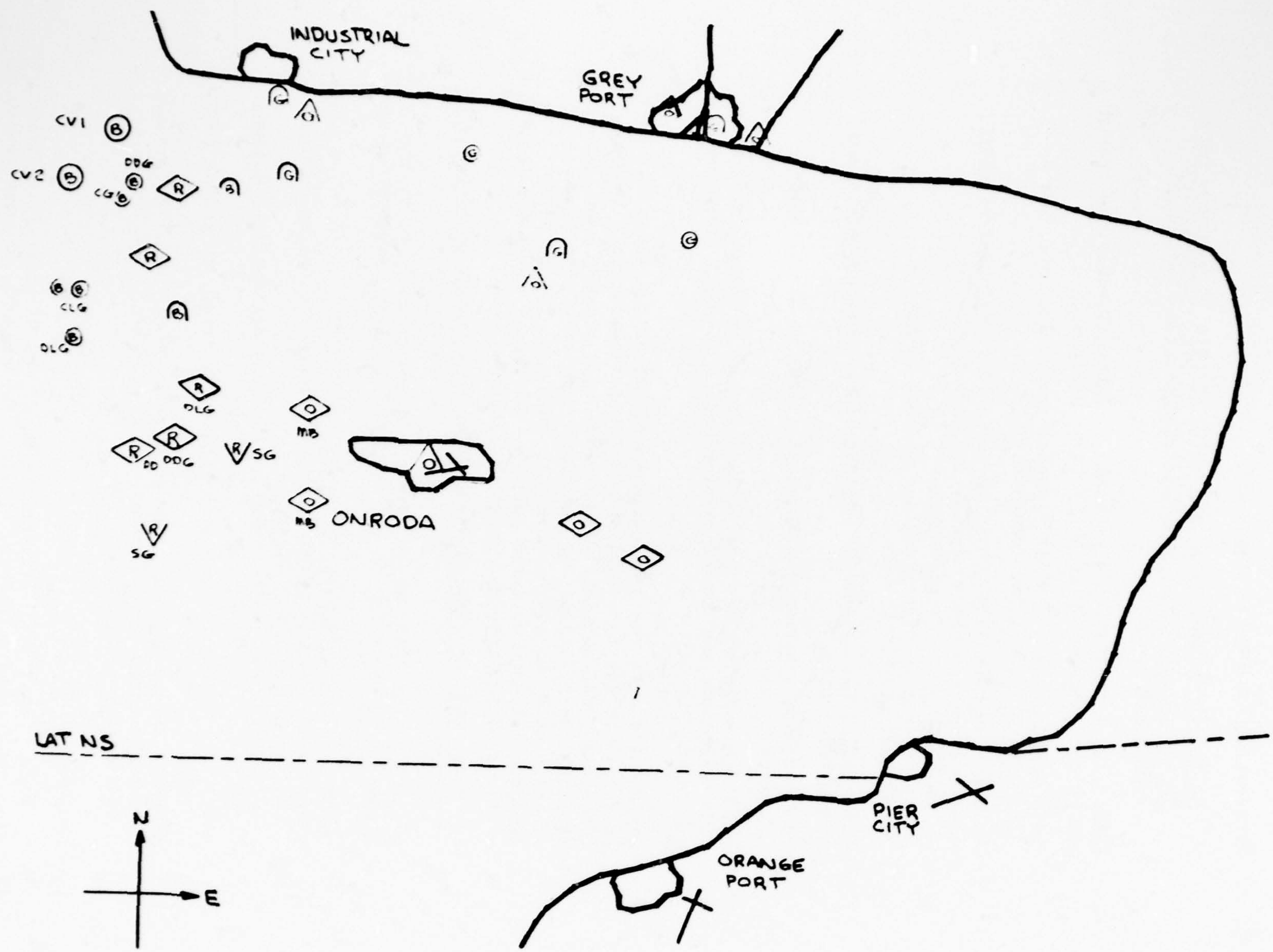
1'. Examples of own courses of action include:

--blockade or military quarantine
--commit sea forces to combat
--commit air forces to combat
--show of military force
--airlift personnel or supplies
--threaten to, or actually, withdraw support
--reposition forces
--commit support services
--conduct military maneuvers or training exercises
--improve force readiness
--provide supplies]

[The simulation board is now altered to show the detailed locations and types of all relevant friendly and enemy forces (Display 2).]



DISPLAY 1: SIMULATION MAP



DISPLAY 2: LOCATIONS OF FORCE UNITS

C. Alternative Evaluation--Airstrike

1. Select the course of action which appears to have the best chance for success. Trace out planned movement on the simulation board.

[Airstrike is tentatively selected. Planned movement is traced out by the commander Display 3) is as follows:

--Air defense unit (1xF14)* returned to CV1 and other air defense unit (1xF14) returned to CV2

--CV2 and support ships moved to position 250nmi west of ONRODA
  --DLG to engage Orange surface defense (1xMB) on northwest side of ONRODA
  --CLG to engage Orange surface defense (1xMB) on west side of ONRODA

--DDG and CG set up surface defense midway between ONRODA and Industrial City

--CV1 sends air strike (1xF14, 1xA7, 1xA6) to attack ONRODA from north

--CV2 sends air strike (1xF14, 2xA7) to attack ONRODA from east and intercept any Orange reinforcements arriving from Orange Port and Pier City

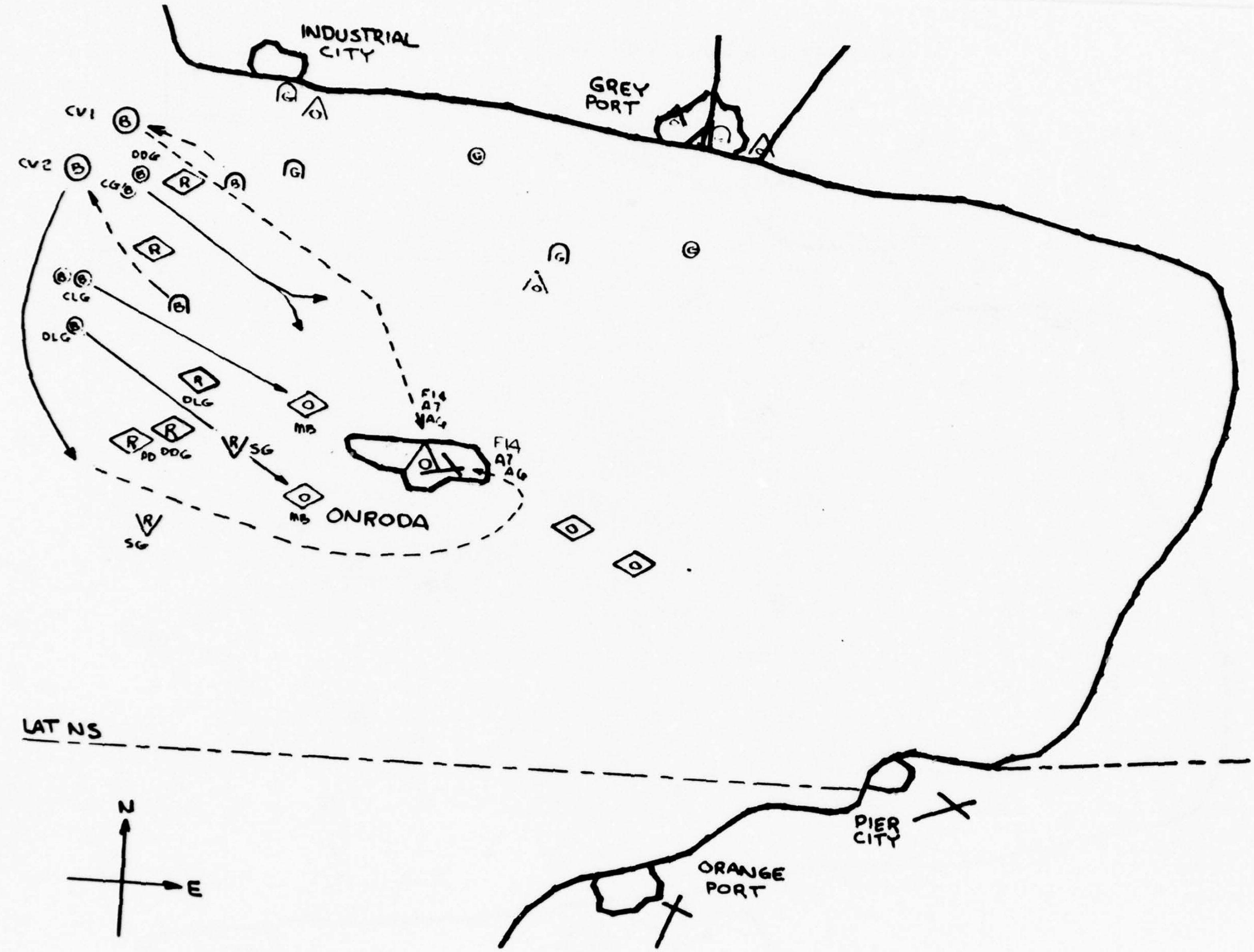
Logic built into the simulation board checks the intended movement pattern for feasibility in view of time/distance factors, transit speeds, movement constraints, and offensive and defensive strength capabilities. An automated version of the board would actually show the pieces moving to highlight forced deviations from the intended movement pattern. Display 4 shows the locations achieved by the intended movement pattern.]

2. Trace out anticipated enemy response movement on simulation board.

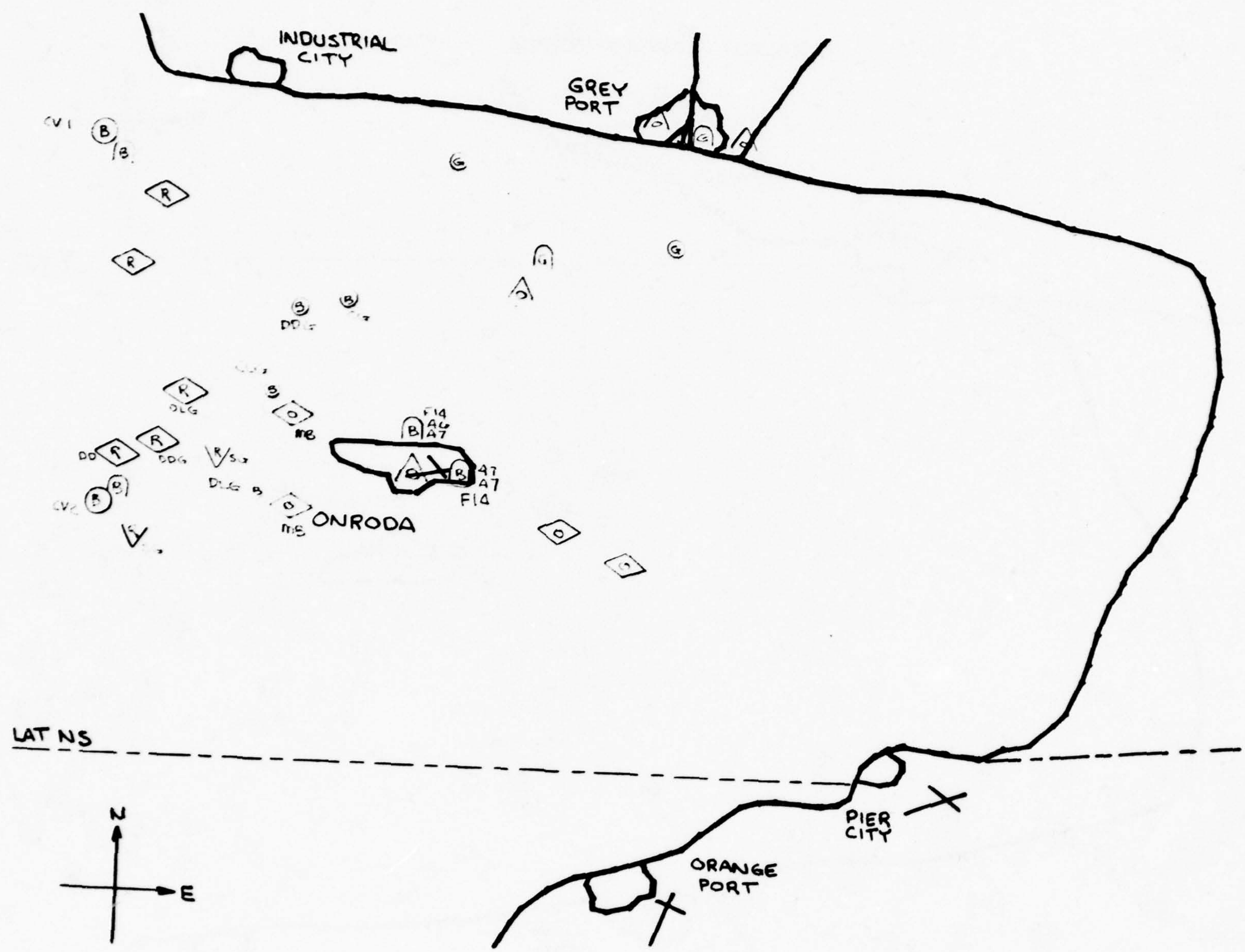
[Unit movement anticipated for Red and Orange as input by the commander is shown in Figure 5. Basic movement assumptions are:

--Red does not attack the task force
--Air reinforcements (2xMIG21 2xMIG19) are brought to ONRODA from Pier City and Orange Port
--Surface defense (4xTB, 2xMB) arrive and join existing defense (2xMB)
--Surviving aircraft from attack on Grey attempt to return to ONRODA
--Orange launches an air defense between ONRODA and CV2 (3xMIG21) with the intent of intercepting and preventing the return of Blue attack aircraft to CV2.]

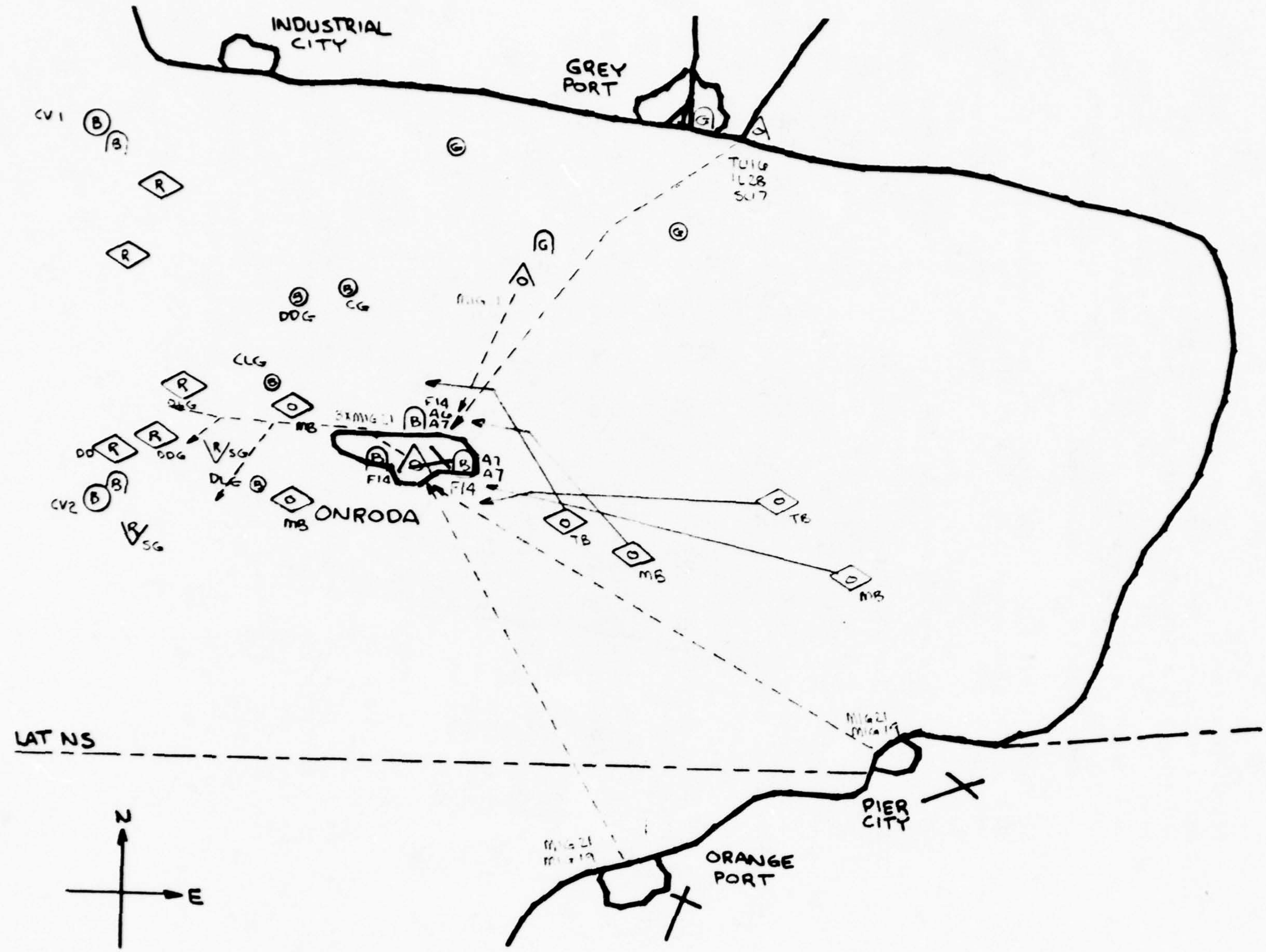
*The symbols "F14," "A6," etc. denote squadrons of aircraft. There are 12 planes to a squadron. Thus, "2xF14," for example, denotes two squadrons totalling 24 planes.



DISPLAY 3: PLANNED MOVEMENT, AIRSTRIKE



DISPLAY 4: FRIENDLY FORCE UNIT LOCATIONS



DISPLAY 5: ANTICIPATED ENEMY MOVEMENTS, AIRSTRIKE

[Given positioning and intended movement patterns, outcome estimation logic built into simulation board estimates enemy losses and generates a probability tree describing possible Blue losses resulting from combat. Losses can result from probability of kill factors relating to the engagement of opposing units or, in the case of aircraft, due to insufficient fuel to permit a safe return to a carrier or land airbase.

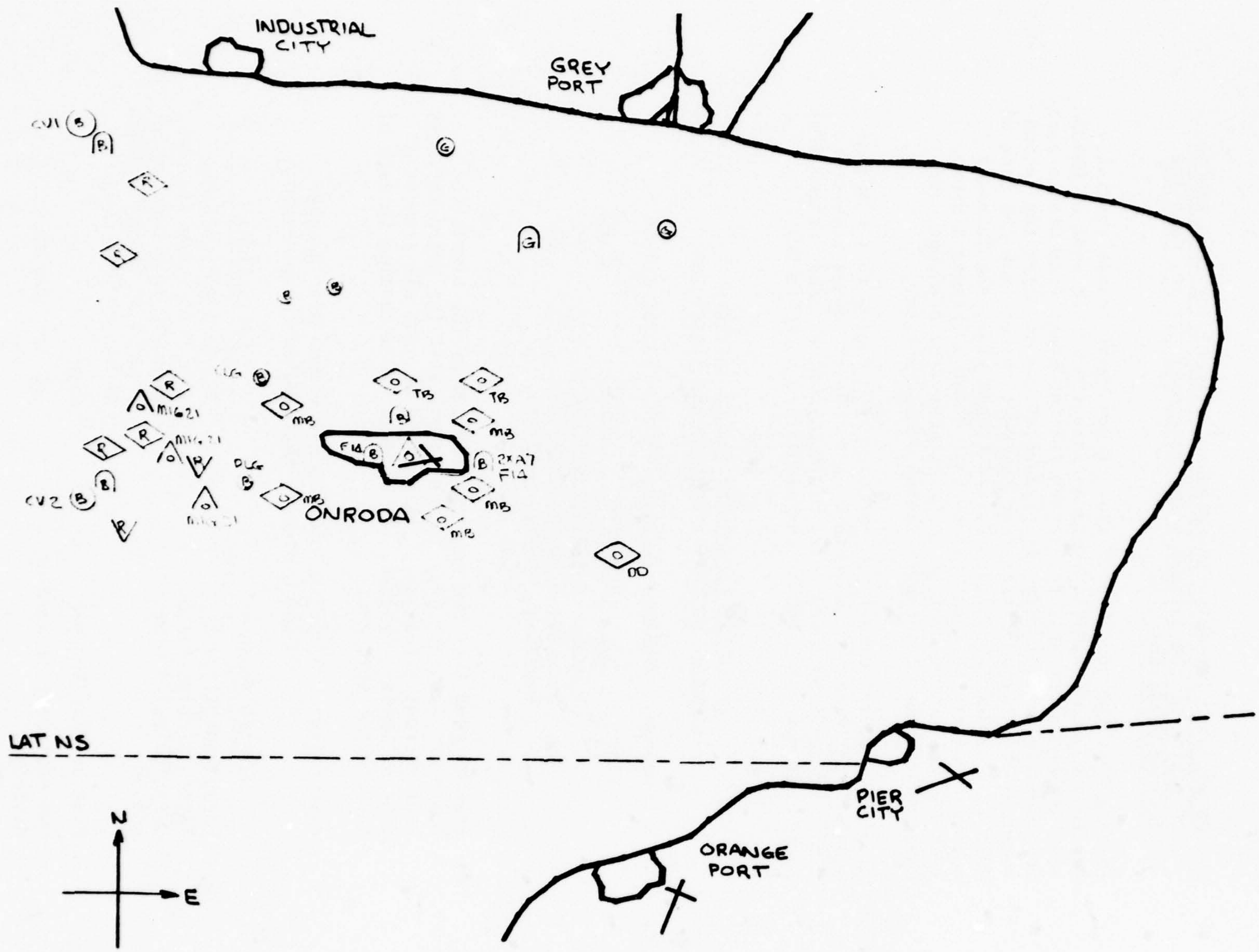
Simulation board logic first simulates the attempted return to ONRODA of the Orange aircraft sent to attack Grey. It is estimated that the Orange attack wave sent to Industrial City incurs heavy losses against Grey base defense (1xMIG21, 1xMIG19, 1xSU7) and against Grey air defense and Blue CAP (1xSU7, 1xMIG21), as does the attack on Grey Port (1xMIG21, 1xMIG19, 1xTU16, 1xSU7). Remaining aircraft (1xMIG21, 1xSU7, 2xIL28, 1xTU16) successfully disengage and begin return to ONRODA. Display 6 shows the unit locations as indicated by the simulation board at this time.

ONRODA combat is next simulated. Heavy Orange losses are indicated (6xMIG21, 1xMIG19, 1xSU7, 2xIL28). Blue losses are estimated for best, nominal and worse case outcomes. Losses occur either as a direct result of the Blue attack or due to Orange counter attacks as input by the user. The table below summarizes total Orange and Blue losses:

ESTIMATED ENGAGEMENT LOSSES
AIRSTRIKE UNDER ANTICIPATED ENEMY RESPONSE

Orange:	9xMIG21, 3xMIG19, 4xSU7, 2xIL28, 1xTU16		
Blue:		Aircraft	Ships
	Minimum:	0.1xF14, 3xA7, A6	0
	Nominal:	0.9xF14, 3xA7, A6	0
	Maximum:	1.6xF14, 3xA7, A6	0

As in the case of Orange losses incurred in the attack on Grey, the simulation board indicates the damage incurred during the ONRODA attack to specific units. Under the nominal case, for example, the user observes that his attack from the east suffers heavy damage (0.9xF14, 2xA7) and is not successful in preventing resupply of Orange aircraft to ONRODA from Orange Port.]



DISPLAY 6: FORCE UNIT LOCATIONS FOLLOWING ANTICIPATED ENEMY MOVEMENTS, AIRSTRIKE

3. Do you wish to revise the planned movement for this course of action or the assumed enemy response? If so, make the desired revisions.

[Noting that the squadron of F14 suffers heavy losses partially due to the Orange missile boats anticipated to the east of ONRODA and that he is not able to prevent reinforcement from Orange Port, the user elects to modify his planned attack to allow the second squadron of F14s to attack from the west rather than the east of ONRODA. Display 7 shows the revised attack plan, the intended movement pattern is identical to that shown in Figure 3 except that the second squadron of F14s attacks from the west. No changes are made to the anticipated Orange action.

Simulation of the attack now indicates 30% damage to the second squadron of F14s in the nominal case. Other losses remain the same. Orange losses and total minimum, nominal, and maximum Blue losses are now estimated by the simulation board to be:

ESTIMATED ENGAGEMENT LOSSES--REVISED
AIRSTRIKE UNDER ANTICIPATED ENEMY RESPONSE

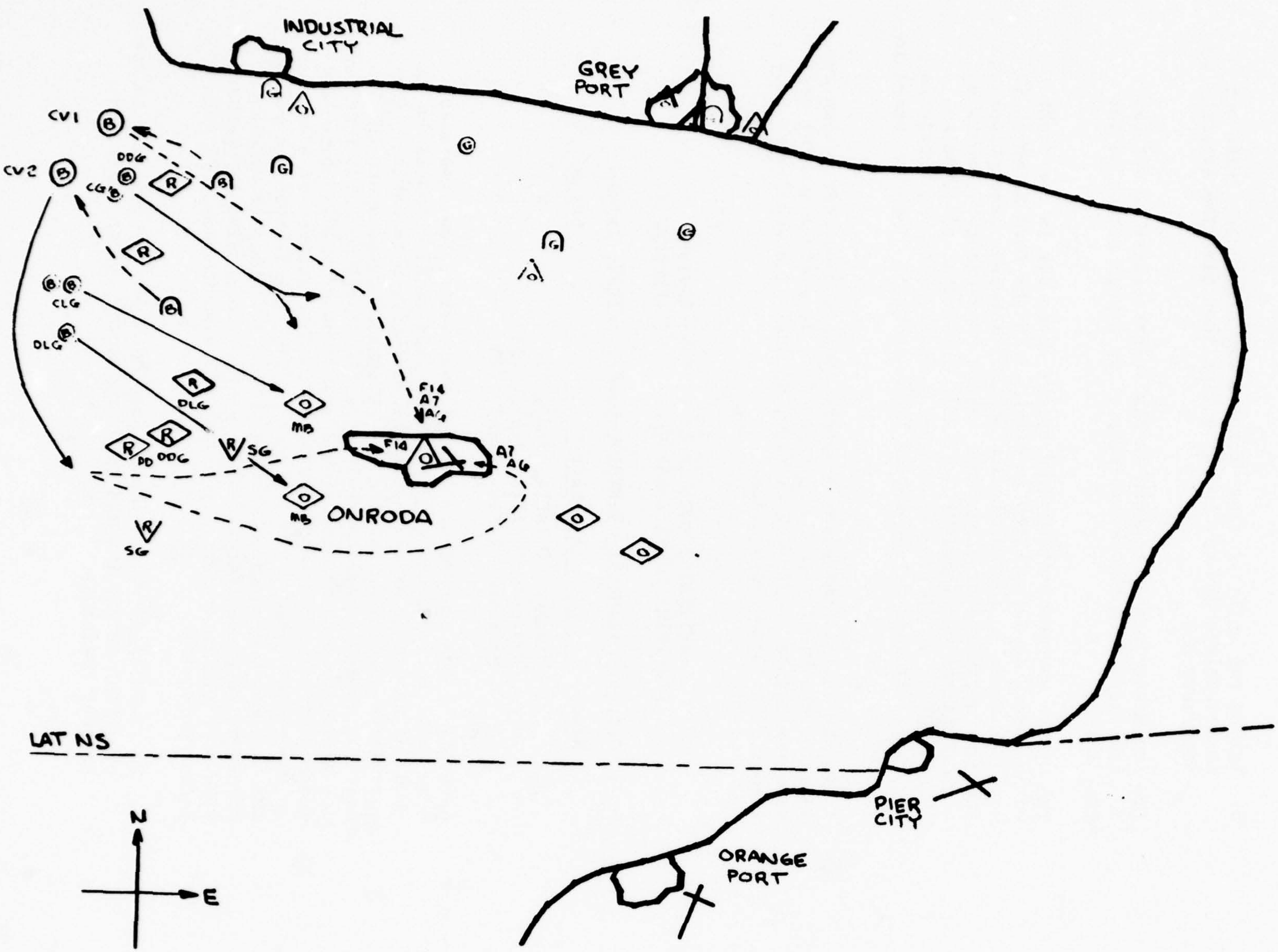
Orange: 9xMIG21, 3xMIG19, 4xSU7, 2xIL28, 1xTU16

Blue:	Aircraft	Ships
Minimum:	0.1xF14, 3xA7, A6	0
Nominal:	0.3xF14, 3xA7, A6	0
Maximum:	1xF14, 3xA7, A6	0]

4. Bear in mind that the results produced by the simulation board are accurate only to the extent that the board reflects your current situation. Taking into account all aspects of your situation, evaluate the alternative according to each of the outcome measures.

Alternative: Airstrike on ONRODA followed with Orange/ ONRODA blockade--anticipated enemy response

Outcome Measure	Evaluation
Enemy capability to launch sorties against Grey following Blue Action	*Orange sustains heavy damage to their aircraft. Unlikely that they would attempt to launch another attack against Grey.*
Risk of Blue/Red War	*High*
Own equipment damaged or destroyed	*Low to moderate*



DISPLAY 7: PLANNED MOVEMENT, REVISED AIRSTRIKE

5. Taking the point of view of the enemy commander, trace out conceivable enemy courses of action that make the alternative look very bad.

[The commander's main concern is his vulnerability to attack. He first considers the possibility of an Orange attack on the task force.

The Orange movement anticipated by the commander in the event of an attack is illustrated in Display 8 in the form in which it would be input to the simulation board. Movement assumptions are the same as in the previous case except that Orange launches an attack against CV2 (6xMIG21, 1XIL28). Positions of opposing forces (after accounting for movement constraints and attrition of Orange aircraft during return from attack on Grey) are shown in Display 9.

As in the anticipated enemy response case, the outcome estimation logic of the simulation board is used to generate a nominal estimate for Orange losses and minimum, nominal, and worse-case Blue losses. Estimated losses are:

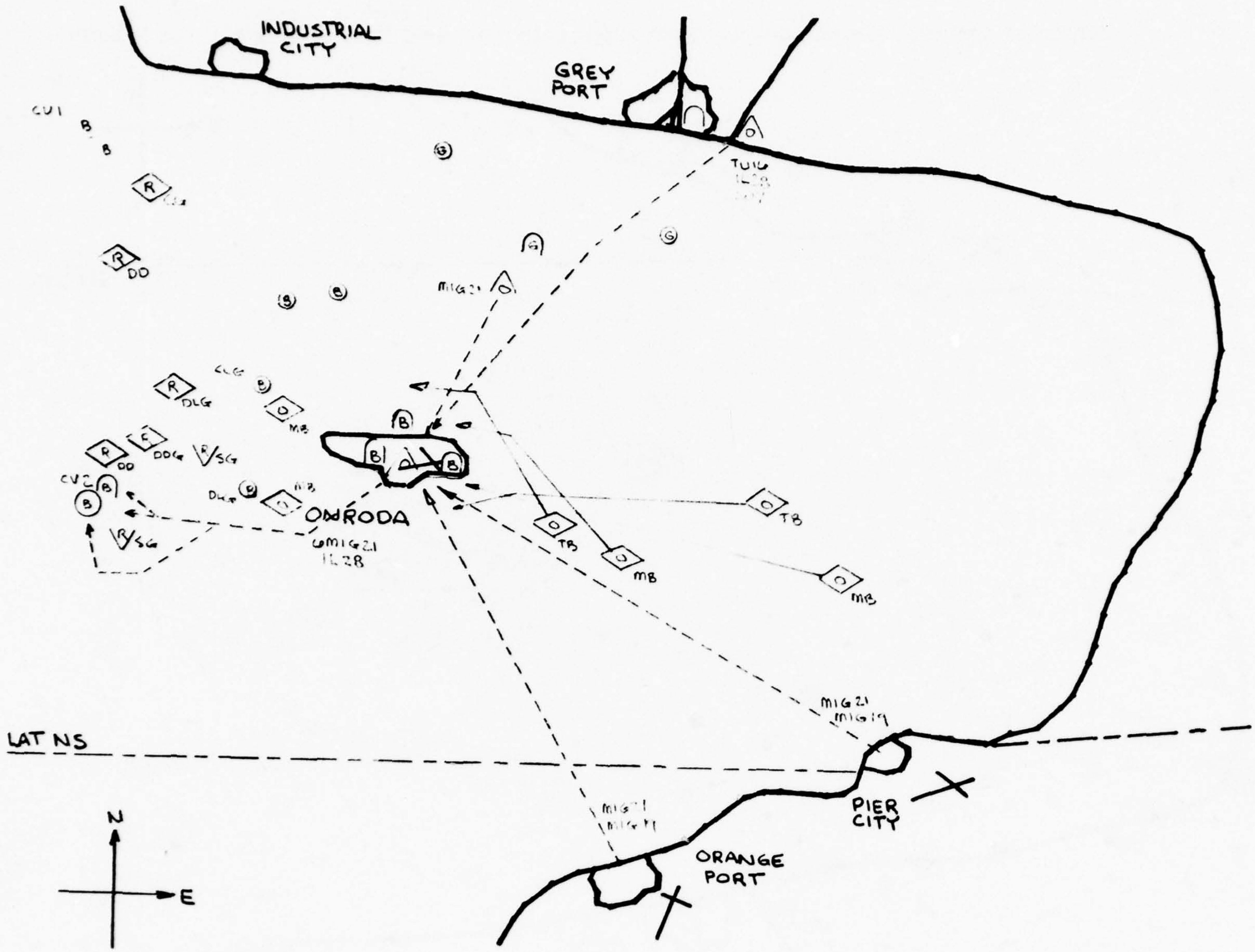
ESTIMATED ENGAGEMENT LOSSES--REVISED
AIRSTRIKE UNDER WORSE-CASE ENEMY RESPONSE #1

Orange: 11xMIG21, 3xMIG19, 4xSU7, 2xIL28, 1xTU16

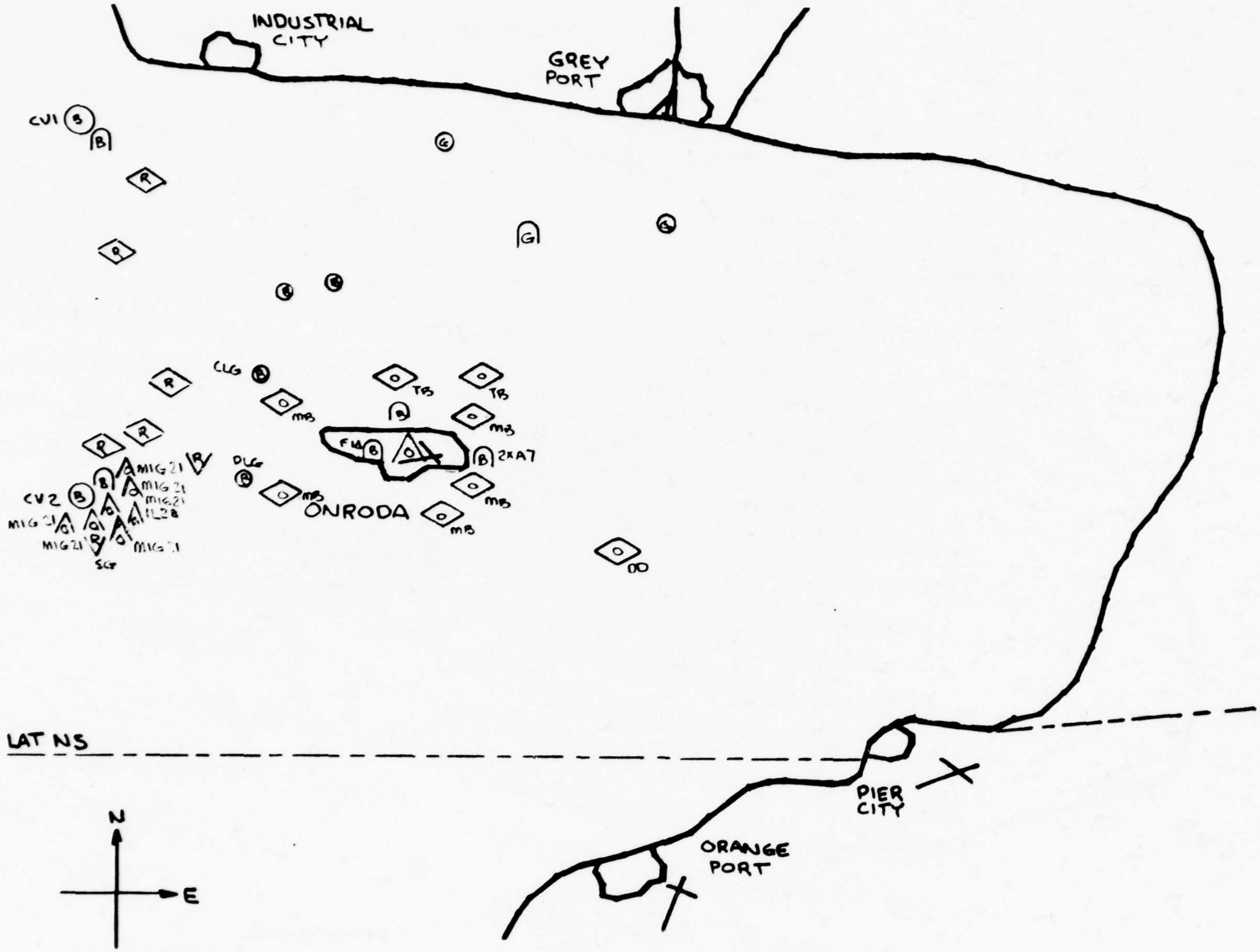
Blue:		Aircraft	Ships
	Minimum:	0.1xF14, 3xA7, A6	0
	Nominal:	0.6xF14, 3xA7, 1.3A6	0
	Maximum:	2xF14, 3xA7, 2A6	0

Contrary to the commander's initial impression, the simulation board does not indicate significantly greater Blue losses in the event of an Orange attack under the airstrike alternative. Comparing the above results with the estimated losses under the anticipated enemy response indicates, if Orange attacks, that Orange can expect to lose two additional squadrons of MIG21s while Blue can expect to lose an additional two tenths squadron of F14s. or about two planes. The explanation for this is that the commander has left one squadron each of F14s, and A6s, to defend CV2. According to probability-of-kill ratios, these planes together with the antiair capability of the ships surrounding CV2 form a potent defense.]

6. Do you wish to revise the planned movement for your own course of action or the assumed enemy response? If so, make the desired revisions.



DISPLAY 8: WORSE-CASE ENEMY MOVEMENTS, REVISED AIRSTRIKE



DISPLAY 9: FORCE UNIT LOCATIONS FOLLOWING WORSE-CASE ENEMY MOVEMENTS, REVISED AIRSTRIKE

[The commander is not now so concerned about an attack by Orange alone, but he is concerned about the threat of Red attack. He therefore traces out the movement anticipated by Red in the event of a Red attack, as shown in Display 10. Movement assumptions are:

--Red and Orange launch a coordinated attack against the task force

--Red attacks CV1 with its three northernmost ships (CG, DD, and DLG)

--Red attacks CV2 with its remaining ships and submarines (2xSG, DD, DDG)

--Red sends its long range bomber (TU20) located at Orange Port towards CV2 and attacks from the southwest

--Orange launches a massive air attack (6xMIG21, IL28) and engages CV2 from the south and east

--Orange reinforces ONRODA with aircraft from Pier City and Orange Port and attempts to return surviving aircraft from attack on Grey as in previous scenario

Positions of opposing forces (accounting for attrition of Orange aircraft from attack on Grey), as indicated by the simulation board, are shown in Display 11.

A nominal estimate for Orange losses and minimum, nominal, and worse-case Blue losses are generated using the outcome estimation logic of the simulation board. Estimated losses are:

ESTIMATED ENGAGEMENT LOSSES--AIRSTRIKE
ASSUMING WORSE-CASE ENEMY RESPONSE

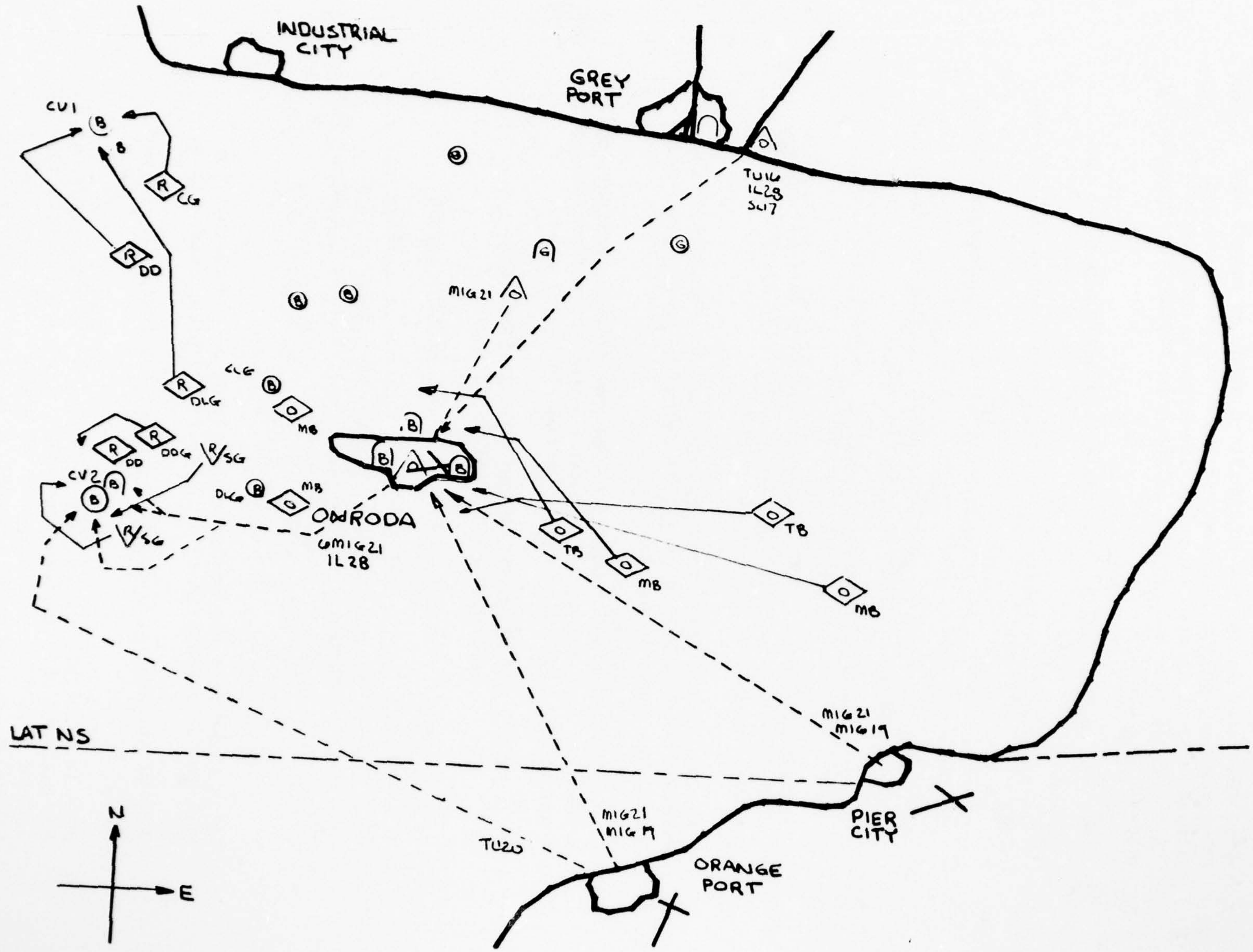
Orange: 7xMIG21, 3xMIG19, 4xSU7, 2xIL28, 1xTU16

Blue:		Aircraft	Ships
	Minimum:	0.3xF14, 3xA7, A6	0.3xDD, 0.1xDE
	Nominal:	0.67xF14, 3.2xA7, 1.2xA6, 0.4SH	1.1xDD, 0.4xDE, 0.3xCV
	Maximum:	3xF14, 4xA7, 2xA6, 2xSH	3.4xDD, 1.4xDE, 1.1xCV

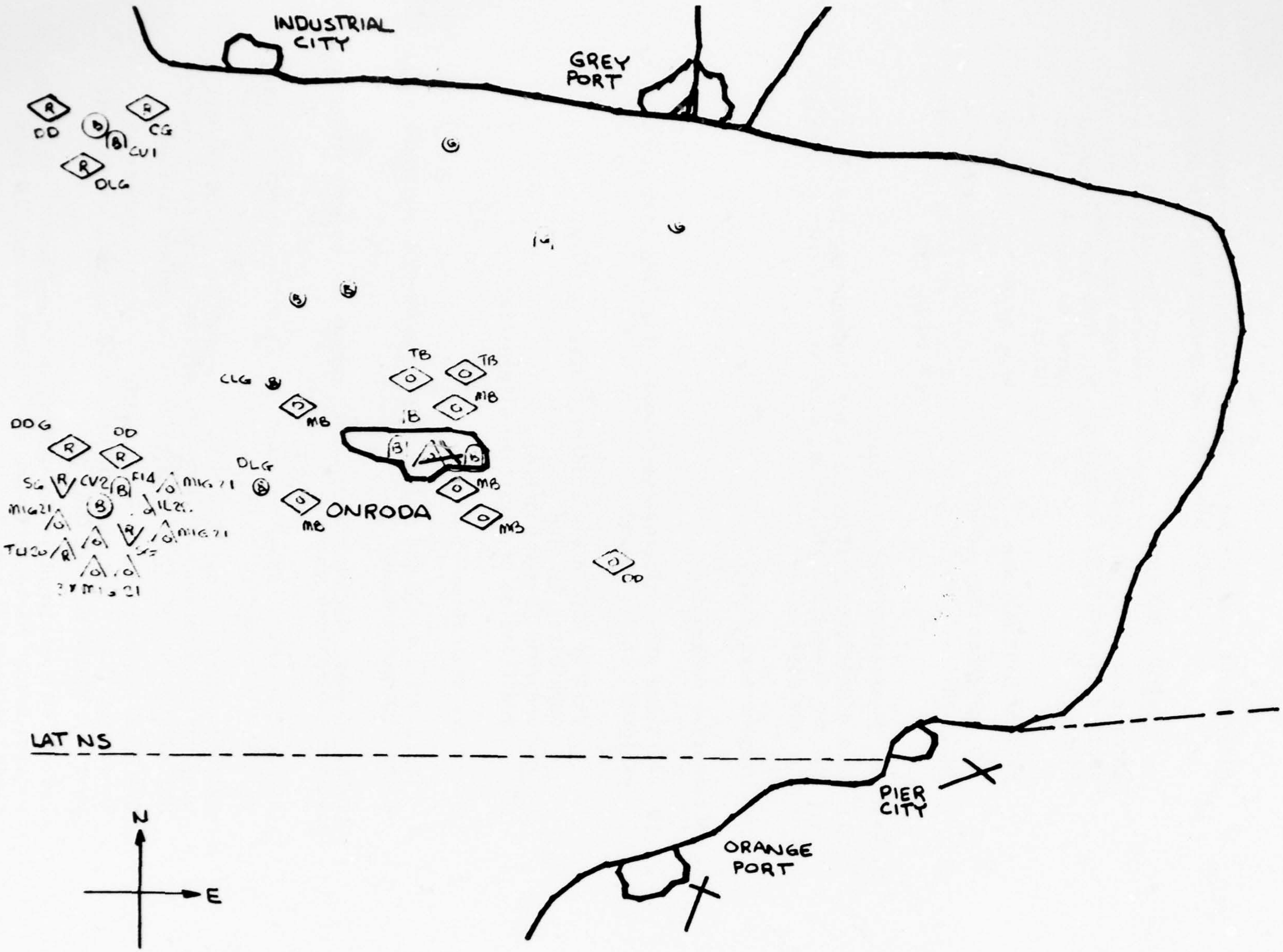
It is clear from the magnitude of estimated losses that the task force is vulnerable to a coordinated Orange/Red attack.

Most of the estimated damage is due to the submarine attack on CV2.]

7. Bear in mind that the results produced by the simulation board are accurate only to the extent that the board reflects your current situation. Taking into account all aspects of your situation, evaluate the alternative assuming the worse case enemy response according to each of the outcome measures.



DISPLAY 10: REVISED WORSE-CASE ENEMY MOVEMENTS, REVISED AIRSTRIKE



DISPLAY 11: FORCE UNIT LOCATIONS FOLLOWING REVISED WORSE-CASE ENEMY MOVEMENTS, REVISED AIRSTRIKE

Alternative: Airstrike of ONRODA followed with Orange/ONRODA blockade--worse-case enemy response

Outcome Measure	Evaluation
Enemy capability to launch sorties against Grey following Blue action	*Orange capability reduced but they have enough air power to launch another attack*
Risk of Blue/Red War	*Very high*
Own equipment damaged or destroyed	*Very high. CV2 almost certain to be lost, 30% chance of losing CV1.*

D. Critical Uncertainty Identification

1. If a significant difference exists between the desirability of the two scenarios, what event or events are most responsible for the difference?

Red attacks task force.

E. Alternative Generation

1. Are there other alternative courses of action that you wish to explore? If so, which?

____ destroy ONRODA airfield with naval gunfire
____ amphibious landing
xxx Grey/ONRODA air blockade
____ modification of airstrike alternative

F. Alternative Evaluation--Blockade

1. Trace out the planned movement for Grey/ONRODA air blockade on the simulation board.

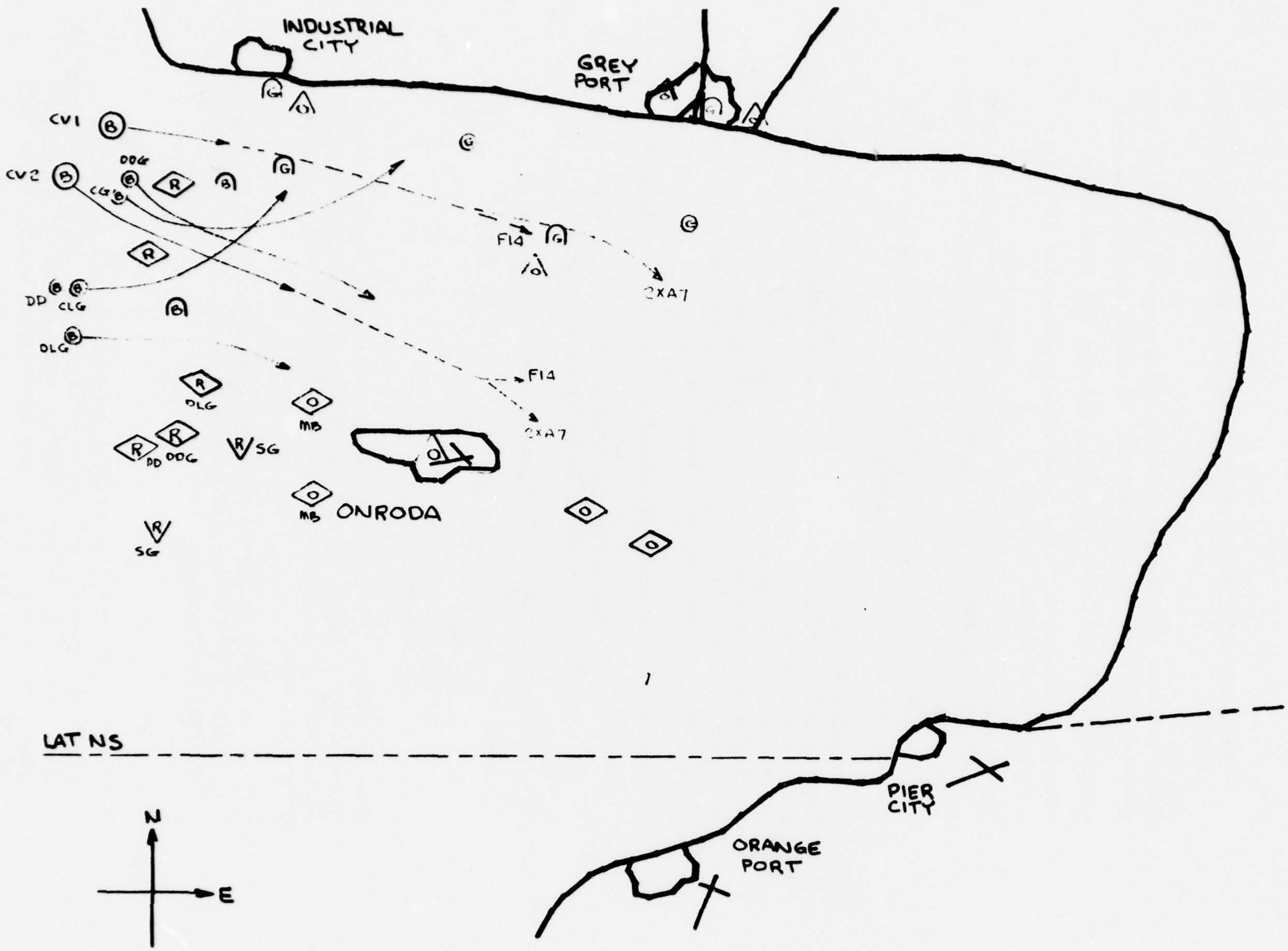
Display 12 shows the planned movement traced out by the commander. Movement assumptions are:

--Air defense unit (1xF14) returned to CV1 and other air defense unit (1xF14) returned to CV2

--CV1 and support ships moved east to a position 50-100 nmi off Grey coast. Air blockade unit (1xF14, 2xA7) sets up secondary CA1 100-150 nmi off Grey Port to deter Orange air strikes

--CV2 moved southeast to a position midway between ONRODA and Industrial City. Air blockade unit (1xF14, 2xA7) sets up primary CAP 50-100 nmi off ONRODA.

--DDG and CG positioned between ONRODA and Grey coast. DLG engages Orange MB to northwest of ONRODA. DD and CLG positioned between CV1 and CV2.



DISPLAY 12: PLANNED MOVEMENT, BLOCKADE

2. Trace out anticipated enemy response movement on simulation board.

Force movement anticipated for Red and Orange as input by the commander is shown in Display 13. Movement assumptions are:

--Neither Red nor Orange directly attacks the task force.

--Orange attempts to break Blue blockade in order to attack Grey Port (4xMIG21, 1xIL28)

--Orange surface fleet engages primary Blue air blockade (2xMB, 2xTB) and remainder (2xTB, 1xMB, 2xDD) engages Grey Port surface defense (1xDD)

--Air reinforcements (2xMIG21, 2xMIG19) are brought to ONRODA from Pier City and Orange Port.

The simulation board indicates that the Orange attack on Grey Port is only partially successful at penetrating the Blue blockade. With the help of their missile and torpedo boats, Orange planes successfully pass around the first blockade; however, when the force ecounters the second blockade, part of the attack force is detained (2xMIG21). The remaining planes reach Grey Port and engage the Grey base defense (2xA4, 1xF4).

Outcome simulation logic estimates the following losses:

ESTIMATED ENGAGEMENT LOSSES--
BLOCKADE UNDER ANTICIPATED ENEMY RESPONSE

Orange: 8xMIG21, 2xMIG19, 4xSU7, 2xIL28, 1xTU16

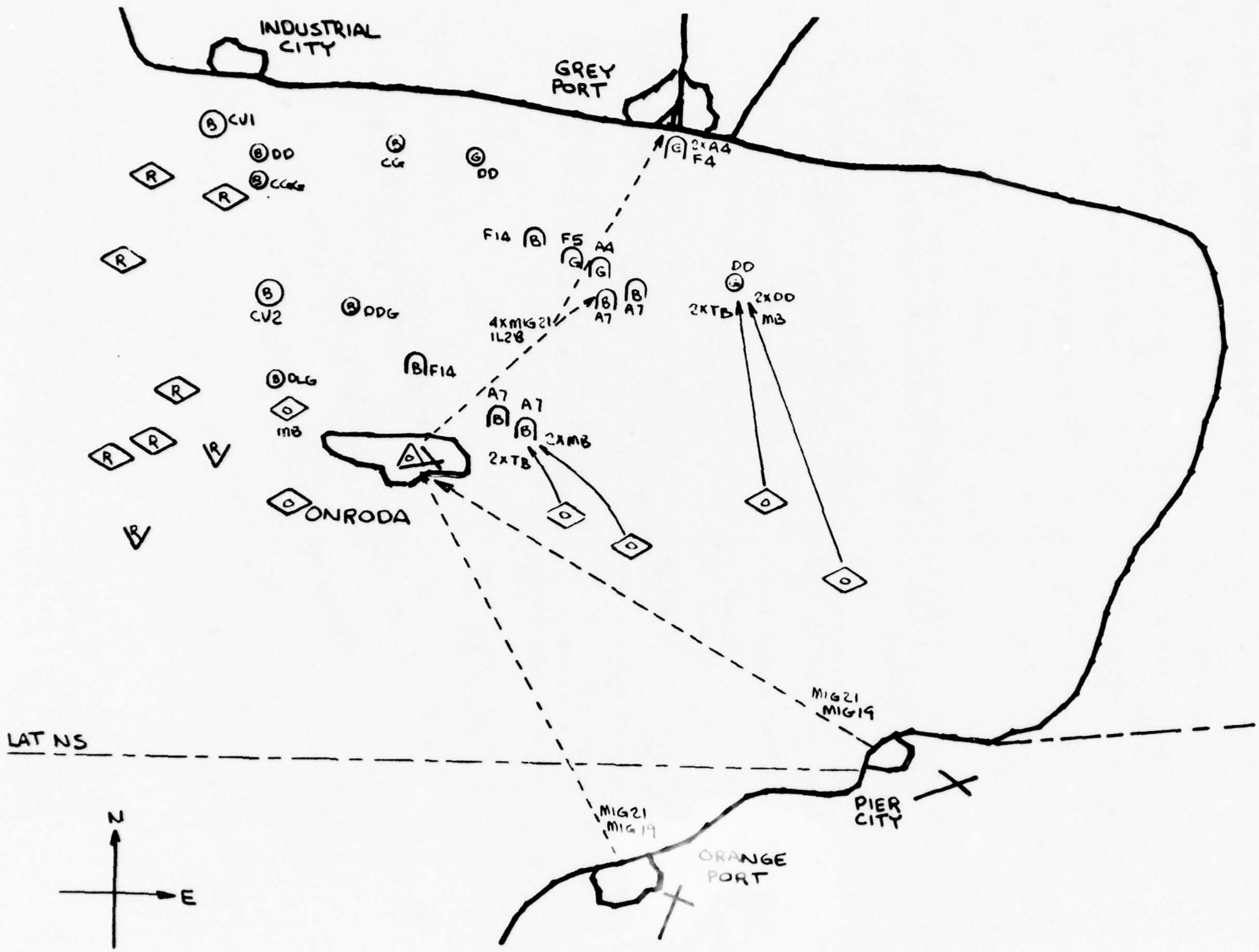
Blue:	Aircraft		Ships
	Minimum:	0	0
	Nominal:	0.3xA7	0
	Maximum:	2xA7	0

Blue air losses are expected as a result of the confrontation at the second blockade. All of the Orange aircraft attempting the attack through the Blue blockade are destroyed or are unable to return to ONRODA.

3. Do you wish to revise the planned movement for this course of action or the assumed enemy response? If so, make the desired revisions.

No.

4. Bear in mind that the results produced by the simulation board are accurate only to the extent that the board reflects your current situation. Taking into account all aspects of your situation, evaluate the alternative according to each of the outcome measures.



DISPLAY 13: ANTICIPATED ENEMY MOVEMENTS, BLOCKADE

Alternative: Grey/ONRODA air blockade--anticipated enemy response.

Outcome Measure	
Enemy capability to launch sorties against Grey following Blue Action	*Orange can penetrate blockade but incurs heavy losses each time they try*
Risk of Blue/Red war	*Moderate*
Own equipment damaged or destroyed	*Low*

5. Taking the point of view of the enemy commander, trace out conceivable enemy courses of action that make the alternative look very bad.

Again, the main concern is a Red attack. The attack pattern input is shown in Display 14. Movement assumptions are:

--Red and Orange launch a coordinated attack against CV2

--Red surface units (CG, 2xDD, 2xSG, DLG, DDG) and air unit (1xTU20) surround CV2

--Orange fighter attack (3xMIG21, 1xIL28) engages CVs from the southwest while combined surface/air attack (4xMB, 2xTB, 1xMIG21) engages the Blue destroyer (DLG) from the south.

--As diversionary measures, Orange sends two torpedo boards (2xTB) to the northeast side of ONRODA and two destroyers to engage the Grey Port surface defense (1xDD).

Outcomes estimates are given below. In this case, simulation indicates significant expected losses for Red.

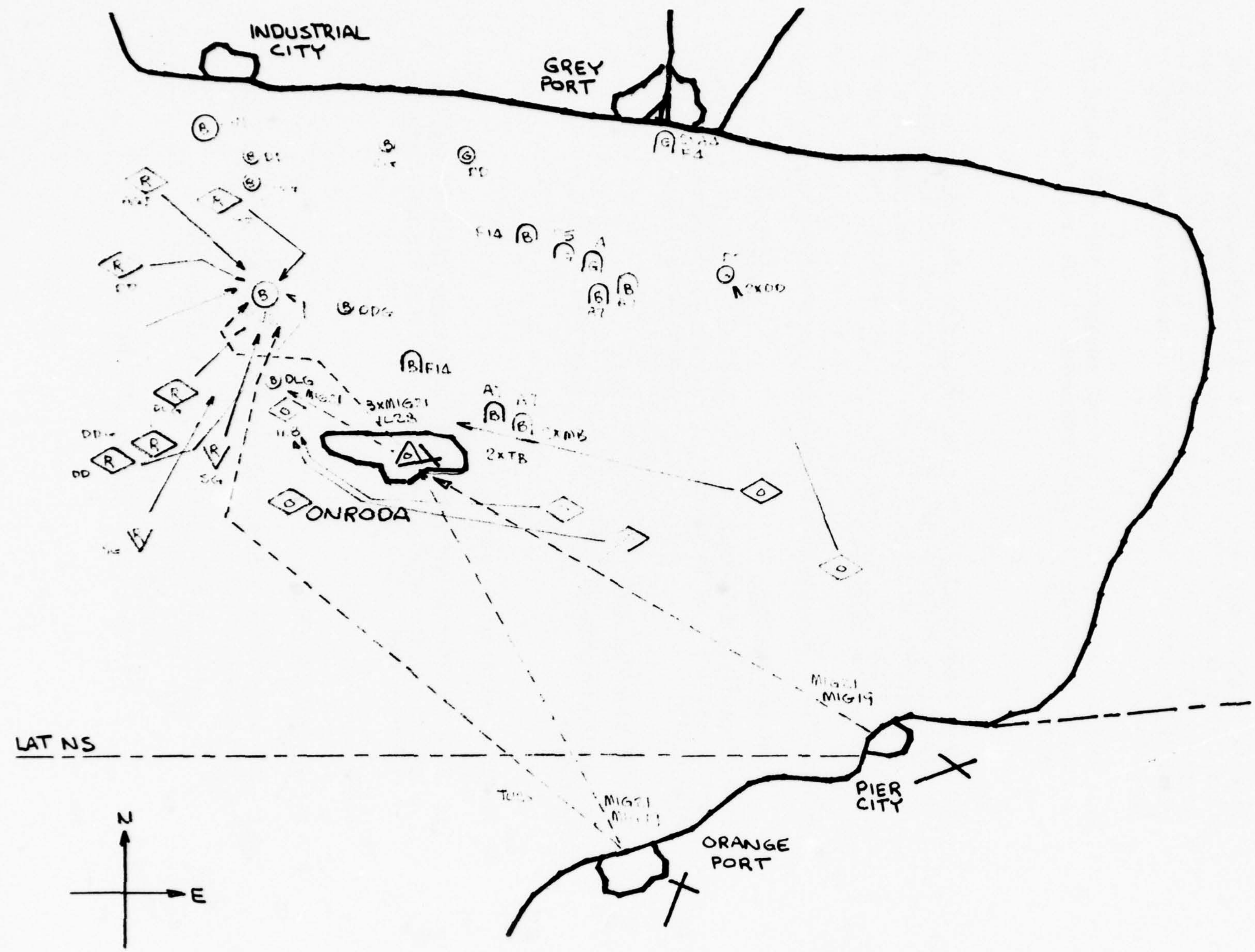
ESTIMATED ENGAGEMENT LOSSES--
BLOCKADE UNDER WORSE-CASE ENEMY RESPONSE #1

Orange: 4xMIG21, 2xMIG19, 4xSU7, 2x1628, 1xTU16

Red: 0.8xCG, 1.6xDD, 0.8xDDG

Blue:		Aircraft	Ships
	Minimum:	0	0
	Nominal:	0.3xF14, A6, SH3	0.2xCV, 0.2xCV, 0.2xDE, 3xDD
	Maximum:	1xF14, A6, SH	1xCV, DE, 3xDD

Much higher losses for Red and lower losses for Blue result under the blockade alternative because of the positioning of the forces. Under the blockade, Blue positions its high-power surface units (DDG, CG, CLG) in locations where they can be used as defense.



DISPLAY 14: WORSE-CASE ENEMY MOVMENTS, BLOCKADE

Because of this, Red must devote all of its forces to CV2, rather than directing some to CV1 to prevent the two carrier groups from merging. Because it is not under direct attack and because of its proximity to CV2, CV1 is able to come to the assistance of CV2. The attacking Red units must retreat.

16. Do you wish to revise the planned movement for this course of action or the assumed enemy response? If so, make the desired revisions.

No

17. Bear in mind that the results produced by the simulation boards are accurate only to the extent that the board reflects your current situation. Taking into account all aspects of your situation, evaluate the alternative according to each of the outcome measures.

Alternative: Grey/ONRODA air blockade--worse-case enemy response.

Outcome Measure	Evaluation
Enemy capability to launch sorties against Grey following Blue action	*Red will be defeated. Orange can penetrate blockade but incurs heavy losses each time they try*
Risk of Blue/Red war	*High*
Own equipment damaged or destroyed	*Moderate*

G. Critical Uncertainty Identification

1. If a significant difference exists between the desirability of the two scenarios, what event or events are most responsible for that difference?

Red attacks task force

H. Alternative Generation

1. Are there other alternative courses of action that you wish to explore. If so, which?

____ destroy ONRODA airfield with naval gunfire
____ amphibious landing
____ Grey/ONRODA air blockade
____ Modification of airstrike alternative

No

I. Sequence and Cause/Effect Relationships

1. Which of the following alternatives are still under consideration for accomplishing the mission?

   xxx airstrike of ONRODA followed with Orange/ONRODA blockade

   xxx Grey/ONRODA air blockade

   ____ Destroy ONRODA airfield with naval gunfire

   ____ amphibious landing

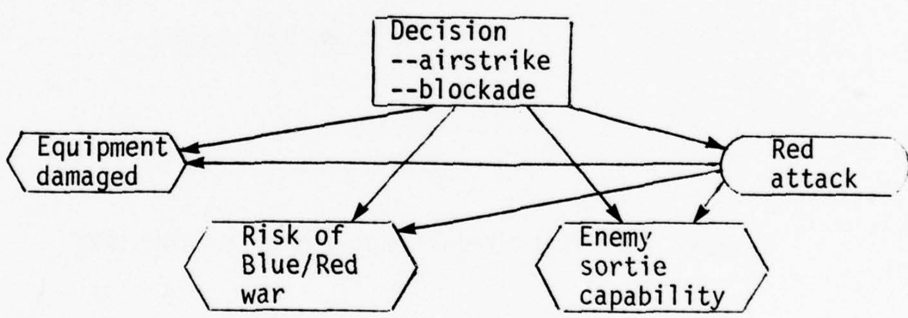
2. Critical uncertain events which have been identified are:

   --Red attacks the task force

   Do you wish to add any others? If so, what?

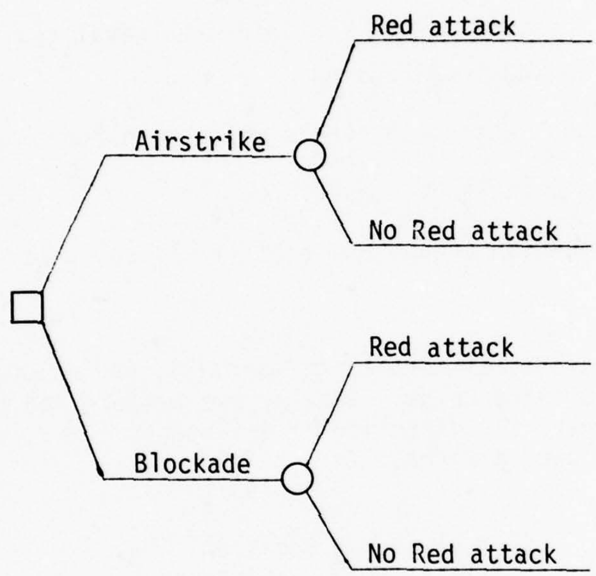
None

3. Decisions, critical uncertainties, and outcome measures are represented below. Draw arrows between the boxes so as to describe the direction of influences (i.e., construct the influence diagram).



J. Preliminary Decision Tree Generation

[The computer checks to see if the influence diagram is a decision network. If so, the decision tree implied is automatically constructed (Display 15).]



DISPLAY 15: PRELIMINARY DECISION TREE STRUCTURE

4. THE EXPANSION PHASE

Decision structuring has been defined as the process of identifying and organizing the factors of a decision into a decision model. In practice, identifying and characterizing a complete list of decision factors is more difficult and requires far more analysis time than does organizing those factors into a decision model.

There is good reason for the emphasis of decision structuring on the search for relevant decision factors. It is very important to account for of the major factors that affect the decision in the decision model. Sensitivity studies of the models developed in decision analysis applications show that small errors in the subjective inputs or the mathematical relationships assumed among variables will usually not change the conclusions of the analysis. On the other hand, omitting some important variable from the decision model can easily affect the analysis to the point that a suboptimal course of action would be indicated.

Earlier phases of the SRI research, in which experimental decision structuring sessions were conducted, pointed out that much of the effort devoted to structuring is focused on a search for and delineation of two types of decision factors: uncertain events that may impact the outcomes to a course of action and new alternatives or modifications to old alternatives that aleviate the adverse consequences of uncertain events. An analysis of

these structuring sessions indicated that the discovery of a new uncertain event with potential adverse consequences often leads spontaneously to the generation of a new or modified alternative. It was concluded, therefore, that the single, most important aid for decision structuring would be a process for enhancing a decision maker's ability to identify important uncertain events that have been previously overlooked. The expansion phase is a systematic process for analyzing an existing decision model to identify sensitive areas where the discovery and addition of overlooked uncertain events is most likely to increase decision model reliability.

4.1 Concept of Operation

This section is meant to provide only a brief summary and an intuitive interpretation of the process by which the expansion phase identifies important decision model areas that require more detail. A complete description of the theory underlying the expansion algorithm is contained in a previous report [12].

Figure 13 illustrates a highly simplified decision tree for representing the example decision situation discussed in Section 1.3. A TFC has a choice between two actions for neutralizing air power on ONRODA Island. He can conduct an airstrike against the Island and follow up with a blockade to prevent resupply. or he can situate his carriers between ONRODA and Grey and set up a protective blockade to prevent the enemy from reaching its target. The only uncertainty represented in the model is the possibility of a Red retaliatory attack against the task force. Notice from the assumed probabilities under the branches representing possible Red reactions, that a Red retaliatory attack is estimated to be four times more

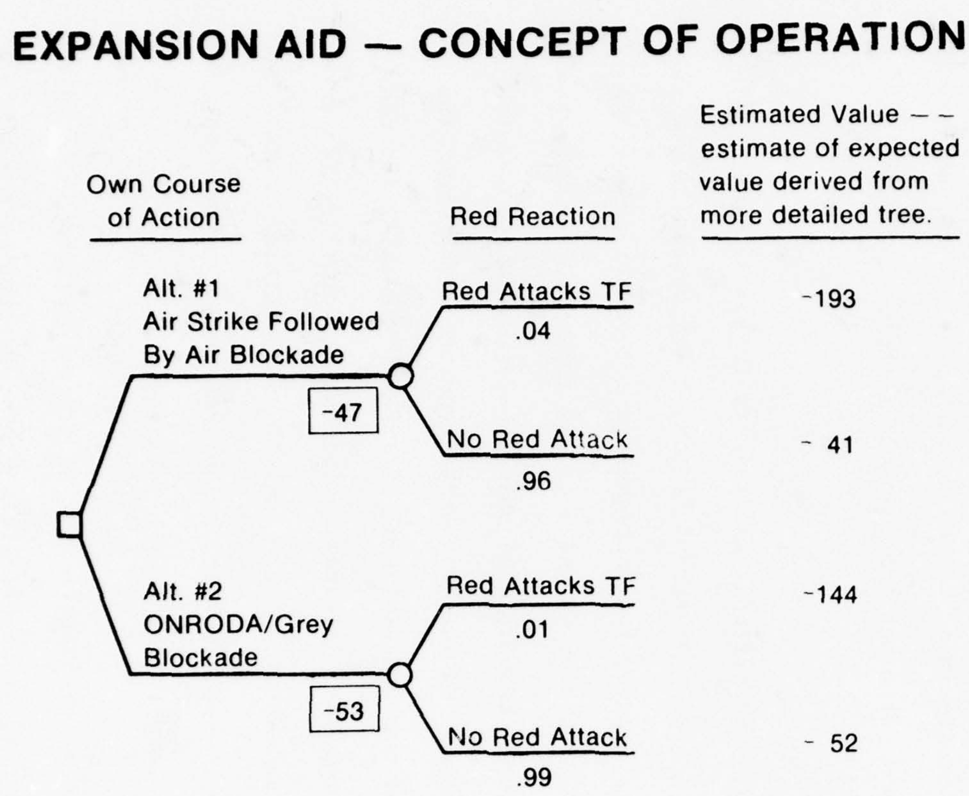


Figure 13 A SIMPLE DECISION TREE

likely if the airstrike alternative is chosen than if the blockade alternative is chosen.

To understand the concept of operation underlying the expansion algorithm, assume that the commander, or someone on his staff, supplies relative value estimates for each path through the tree (shown at the right of the diagram) so that it may be solved to indicate an alternative with highest expected value. With the sample numbers shown, airstrike is slightly preferable.

The difficulty with this simple analysis is in assessing reliable value estimates. Although a number of approaches exist for assessing values, they all require the subject to consider outcomes at a level of detail commensurate with the structure of the decision tree. One such approach would be to ask the subject to imagine that the decisions and events corresponding to each path through the tree occur, to think about the outcomes that would be implied, and then to estimate (usually through trade-off questions) relative preferences for those outcomes. The tree in Figure 13 is so simple that it fails to specify in sufficient detail the outcomes corresponding to each path. For this reason, the decision maker is likely to feel very uncertain about what value numbers to assign.

In principle, the value numbers that should be assigned in the simple decision tree of Figure 13 could be obtained by constructing a much more detailed decision tree containing all of the factors that, because they are omitted from Figure 13, make value assessment difficult. To obtain the proper value number associated, for example, with the topmost path through the tree (airstrike followed by Red attack), the expectation (average

weighted by probabilities) would be taken over all of the values assigned in the more detailed tree to paths that begin with the action airstrike and contain the event Red attack. The decision maker's uncertainty over what values to assign in the simple tree can be interpretted as due to the fact that the more detailed tree has not been constructed and analyzed to obtain appropriate values in this way.

Figure 14 again shows the simple decision tree, this time with illustrations of the probability distributions that might represent a decision maker's subjective uncertainty about what expected values might be obtained if the detailed decision tree were constructed. As can be deduced from the widths of the distributions, the decision maker feels more uncertain about estimates for the value of scenarios where a Red attack occurs than he does about estimates for the value of scenarios where a Red attack does not occur. If the user feels very uncertain about the value at the end of a path, then adding more detail to the path can be expected to resolve considerable uncertainty. Conversely, if the user does not feel much uncertainty, then adding more detail is not likely to resolve much uncertainty.

If a user wanted to improve the reliability of a simple decision tree, it might at first seem that more detail should be added to the paths where outcome value uncertainty is the greatest. There is, however, another consideration--the amount of change in the value estimate that would be required to switch the decision. The dashed lines and arrows in Figure 14 show the amounts by which the estimated value for each path would have to change (leaving the other values constant) to produce a switch in the

EXPANSION AID — CONCEPT OF OPERATION

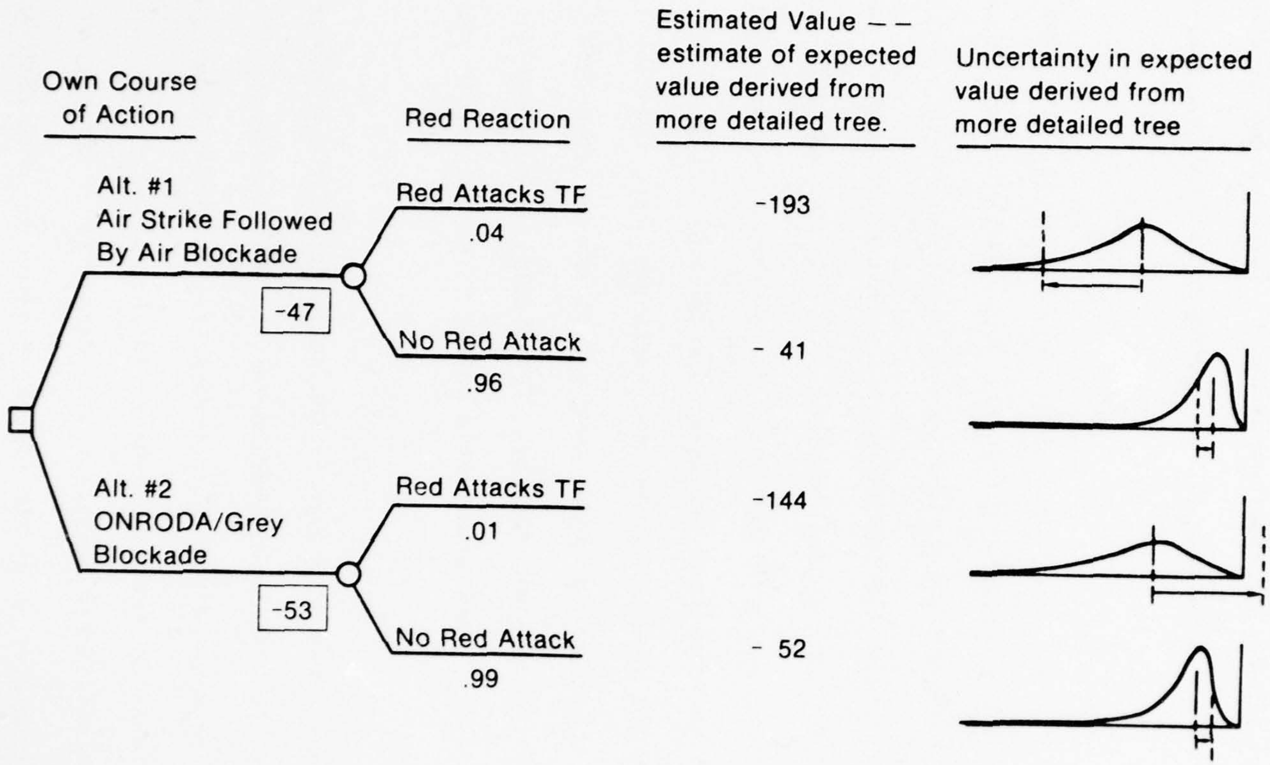


Figure 14 DECISION TREE AND DECISION MAKER'S SUBJECTIVE UNCERTAINTY ABOUT OUTCOME VALUE ESTIMATES

alternative with the highest expected value. It can be seen that resolving uncertainty in the value associated with the path airstrike followed by no Red attack is most likely to indicate that the simple model has incorrectly identified the optimal decision. Intuitively, then, this is an important scenario to structure further so as to improve the reliability of the model.

The expansion phase of the structuring process operates according to this concept. A computer program calculates the value of resolving outcome uncertainty along each path through a current decision tree model. The path with the highest value of eliminating outcome uncertainty is specified and used to generate questions to identify important uncertain events that have been omitted from the tree.

4.2 Expansion Phase Functions

Figure 15 shows the functions executed in the expansion phase. The figure distinguishes between those structuring functions that require human judgment and, therefore, must be performed by the user (shown in boxes with right-angled corners) and those functions that a computer can perform independently (shown in boxes with rounded corners). As described earlier, because outcome calculators and a value model are not unique to a specific decision, they can be developed before the time they are needed and supplied to the structuring process as prestructured models. Prestructured models are represented in the flowchart by six-sided boxes.

The process starts at the top of the flowchart. It is assumed that a preliminary decision tree has been specified and provided as input. The first step is to estimate and assess ranges of uncertainty for the outcomes

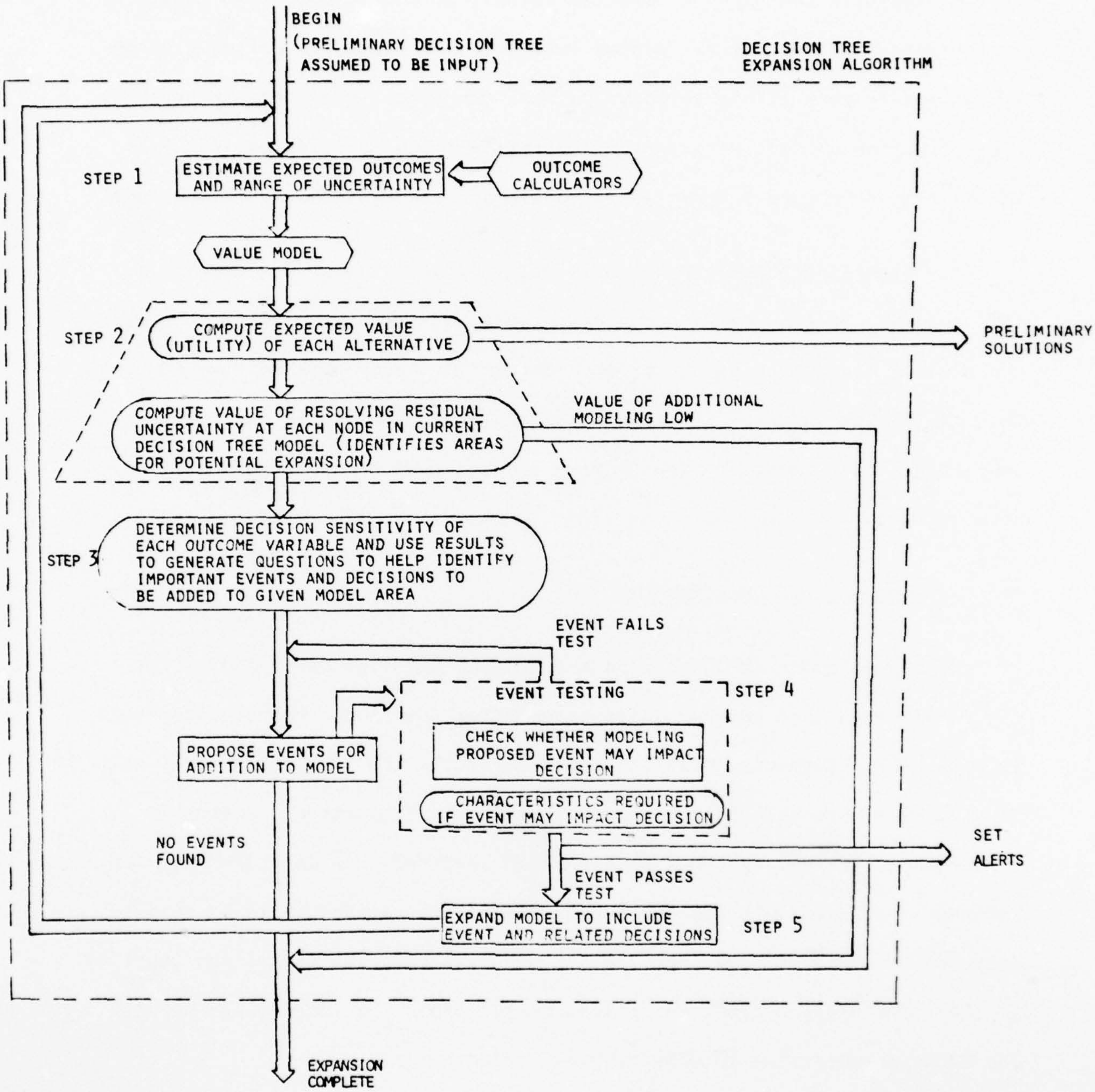


Figure 15 FLOW CHART OF DECISION TREE EXPANSION ALGORITHM SHOWING TASKS FOR STAFF: ▭, COMPUTER: ⬭, AND PRESTRUCTURED MODELS ⬡

expected for each path through the preliminary decision tree. Outcome calculators may be used to help generate these estimates, but it is important that the uncertainty ranges used accurately reflect the commander's confidence in the estimates.

The second step is to solve the decision tree and to compute the value of resolving residual outcome uncertainty at each node in the tree, thereby indicating areas needing more detail. Once the areas for expansion are identified, the third step is to generate questions designed to identify uncertain events to be included in the model areas needing expansion. The method for generating the questions is to compute the decision sensitivity of each outcome variable. The outcome variable to which the decision is most sensitive forms the focal point for the question. For example, suppose the most sensitive outcome variable for the scenario corresponding to the path through the tree with the highest value of further modeling was aircraft losses. The prompting question would ask the decision maker to imagine that the identified scenario were to occur, and then to think of events that could cause the number of aircraft losses to be significantly different from his original estimate. The exact manner in which this technique is implemented to encourage the generation of overlooked events is illustrated in the exhibit in Section 4.3.

Events that are proposed for addition to the decision tree are tested in Step 4 to check whether they might have sufficient impact on the model to influence results. The reason for testing newly identified factors before including them in the model is to avoid modeling effort in those cases where the effort would not affect the recommended decision strategy. The method

of testing is to assess a rough estimate of the probability that the newly identified event will occur. The probability that would be required in order for the event's inclusion in the model to affect the decision is then calculated. If the estimated probability is greater than or equal to the required probability, then the fifth step, expand the model to include the new event, is executed. Since, in practice, new alternatives are sometimes generated in response to a newly proposed event, any modeling effort conducted in Step 5 will also be directed toward including newly identified alternatives in the decision tree structure.

The arrow in Figure 15 from Step 5 back to Step 1 indicates that the expansion phase is an iterative process. The steps of the process are repeated until the analysis indicates a value of additional expansion sufficiently low enough that the resource costs of further analysis are not warranted.

4.3 Aids for the Expansion Phase

The primary aid for the expansion phase is an interactive program for decision tree expansion and analysis. This program may be used with or without auxiliarly aids for simplifying the generation of required inputs. Auxiliary aids that can be used with the program include outcome calculators and aids for probability encoding and value model development.

The initial implementation of the program for decision tree expansion and analysis was undertaken using conventional computer terminals with limited graphics capabilities located at SRI International. The program was then transferred to the ODA test bed. Recent programming effort has

concentrated on developing graphics that make use of the advanced display capabilities at the test bed, streamlining programing to improve convenience and flexibility, and making minor algorithm modifications to improve operation. A technical description of the program has been presented in a previous report [12] and will not be repeated here. The following subsections briefly summarize the current program status and recent improvements.

4.3.1 Graphics Implementation

Delays in the installation of graphics hardware and software and some recent equipment failures at the ODA test bed have made it impossible to complete implementation of newly designed I/O graphics during this phase of the research program. Nevertheless, considerable progress has been made. The majority of the graphics capabilities are now operational. Decision trees may be drawn and displayed in a natural manner; string and box plots may be used to display the minimum, maximum, and nominal estimates for uncertain variables. Graphics color is used to increase the quantity of information that can be conveniently displayed. Color reproductions of photographs, showing the display capabilities of the program as currently available at the test bed, were included in a recent SRI status report [17].

The current graphics implementation is incomplete in two respects. First, not all graphics manipulation functions have been implemented; so, the full flexibility of displays is not yet available. Second, the desired format for specific displays has not been fully implemented. Figures 4 through 6 in Section 2 and the displays in the exhibit in Section 4.4 show the format for specific displays used in the expansion phase. Except for

the use of color in the actual displays, the black and white illustrations show the current graphics design as it will appear when implementation is complete.

4.3.2 Improved System Efficiency and Flexibility

A number of important changes have been made to improve the efficiency and flexibility of the expansion program. The use of multiple workspaces enables the parallel processing capability of the DAISY software system at the test bed to be used. Data are now referenced and retrieved with consistent bookkeeping subroutines. These two changes significantly accelerate program execution.

Program structure has been redesigned to improve flexibility. The user is no longer forced to execute the various steps of the algorithm in a strict sequential fashion. Program modules have been restructured to allow the user to freely move from one operation to another. This new design allows the user inputs made in previous steps to be more easily modified and permits larger or more tedious problems to be analyzed in parts, stored, and then later retrieved for further analysis.

4.3.3 Redesign of Probabilistic Processing and Event Testing Subroutines

The subroutines used for probabilistic processing have been redesigned. Uncertainties are now approximated using beta distributions. Beta distributions are more general than normal distributions in that they can be used to represent skewed (nonsymmetric) as well as symmetric distributions. The capability of representing distributions that are skewed is important for decision problems containing uncertainties with expected deviations that

are larger on one side of the nominal estimate than the other. Uncertainties over own force losses, for example, may be skewed to one side or the other of the nominal estimate, depending on circumstances.

The algorithm used for testing new factors proposed for addition to the decision tree has also been redesigned. The new design is illustrated in the exhibit in Section 4.4. It requires fewer quantitative inputs and speeds up the testing function.

4.4 Sample Application of the Expansion Aid

Exhibit 2 illustrates the use of the automated aid for the expansion phase through the continuation of the sample application description begun in Exhibit 1, Section 3.3. The computer is called on to supply considerably more processing support in the expansion phase than in the preliminary structuring phase, and therefore more quantitative inputs are required. A major objective of the design of the expansion algorithm has been to make use of approximation so as to streamline the inputting of data to keep time and data requirements to an acceptable level. As in Exhibit 1, the description of the process has been outlined for clarification according to the principal structuring functions.

EXHIBIT 2: SAMPLE APPLICATION--EXPANSION PHASE

A. Estimate Event Probabilities, Expected Outcomes, and Ranges of Uncertainty

If the user elects to continue the structuring process into the expansion phase, he must first provide the quantitative inputs to the preliminary decision tree. This requires the assessment of probabilities for each uncertain event in the tree and the assignment of values (utilities) for representing the decision maker's preferences for the scenarios represented by the paths through the tree. The recommended method for assigning values consists of three steps: (1) define outcome variables for quantifying the outcome measures developed in the preliminary structuring phase, (2) estimate each outcome variable for each path through the tree (e.g., by hand or using prestructured outcome calculators), (3) convert outcome estimates for each path to a single number (representing overall preference for that path) using a value model. Specific aids for assessing probabilities and developing values are not provided with the current aid. Several computer programs for assisting the elicitation of probabilities and developing value models are already in existence [18,19].

1. Probabilities of Critical Uncertainties

The preliminary decision tree is shown in Display 15 of Exhibit 1. In this example application, the probability of a Red attack under the airstrike option was estimated to be 0.04. The probability of a Red attack under the blockade option was estimated to be 0.01.

2. Outcome Variables and Value Model

In the example application, outcome variables were chosen to correspond to the measures defined in the preliminary structuring phase. For own equipment damaged, outcome variables were chosen to represent the fraction of damage to critical aircraft and ships. The outcome variable for enemy sortie capability was chosen to be the number of potential Orange sorties that could be launched from ONRODA in a three-month period following the Blue action. The outcome variable for the risk of Blue/Red war was chosen to be the commander's subjective probability that Red would directly attack Blue nation.

A linear, additive value model was used to indicate the relative importance of outcome variables:

$$V = - x - 7y - 0.003z - 912w$$

where

$$x = 6[\text{F14s lost}] + 3[\text{A6s lost}] + [\text{A7s lost}]$$

represents aircraft losses in A7 aircraft equivalents, and

$$y = 2.5[\text{CG cap. lost}] + 25[\text{CV cap. lost}]$$

gives ship losses in DLG ship equivalents, The number of potential Orange sorties from ONRODA during the three-month period following the Blue action is z, and w is the probability that Blue-Red war results.

3. Outcome Estimates

Display 16 illustrates the use of the computer aid for eliciting outcome estimates. The computer asks the user to enter best, low, and high estimates for the expected value of each outcome variable. Estimates are requested for each path through the tree. The path addressed in the display is airstrike followed by no Red attack. User inputs are underlined.

B. Identification of Model Areas for Expansion

As the outcome estimates are input, the computer fits a probability distribution (based on beta functions) such that the best estimate is the median, and the low and high estimates are the 10% and 90% points of the distribution. The program then calculates a distribution on overall outcome value for each path through the tree, solves the tree, and then calculates the value of resolving the uncertainty in outcome value for each path through the tree.

Display 17 illustrates the manner in which the computer summarizes results. The display shows the decision tree and the decision strategy with the highest expected value. Although not visible in the black and white reproduction, the computer highlightes the path with the highest value of further modeling by coloring it red. In this case, the path with the highest value of modeling is airstrike followed by no Red attack.

OUTCOME ESTIMATION

ENTER BEST (50%), LOW (10%), AND HIGH (90%) ESTIMATES FOR THE EXPECTED VALUE OF EACH OUTCOME VARIABLE BELOW. ASSUME THAT THE ALTERNATIVE CHOSEN IS "AIR STRIKE" AND THAT THE EVENT "NO RED ATT" OCCURS.

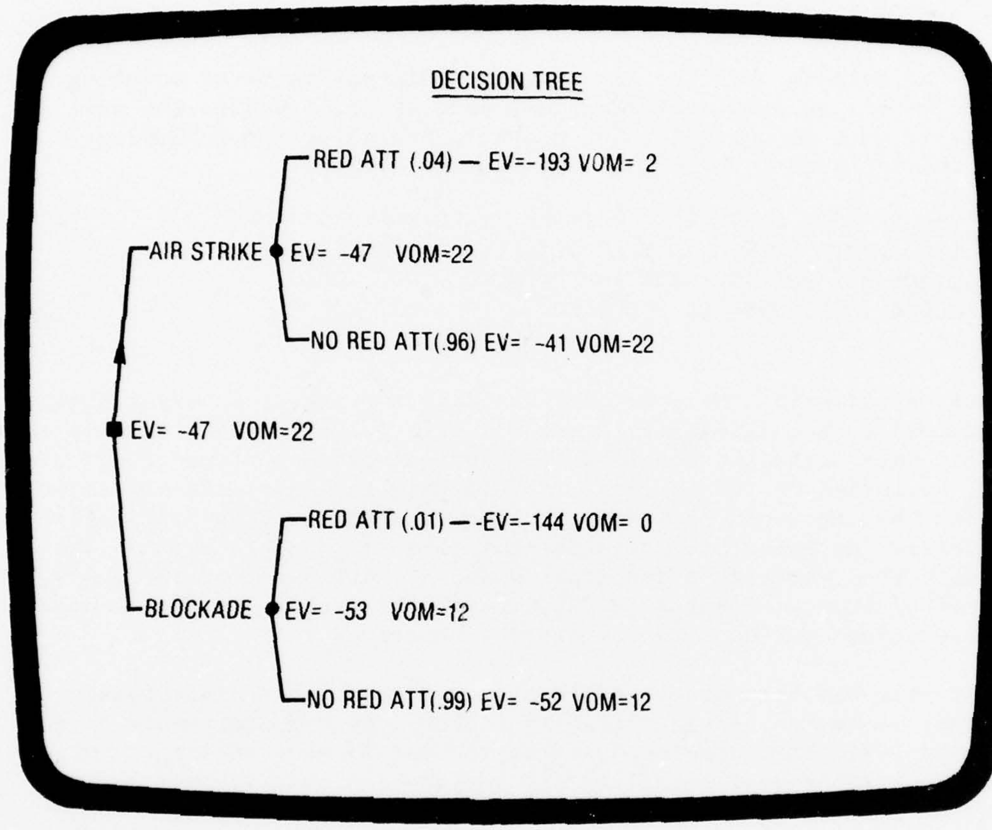
AIR LOSS

F14 BEST ESTIMATE: 4 LOW ESTIMATE: 1 HIGH ESTIMATE: 9

A6 BEST ESTIMATE: 1 LOW ESTIMATE: 0 HIGH ESTIMATE: 3

A7 BEST ESTIMATE: 1 LOW ESTIMATE: 0 HIGH ESTIMATE: 6

Display 16 GRAPHICS DISPLAY USED FOR OUTCOME ESTIMATION



Display 17 DECISION TREE DISPLAY

C. Generate Questions for Identifying Important Events

To assist in identifying events to add to the decision tree, the computer conducts a sensitivity analysis to identify which outcome variable-- aircraft lost, ships lost, Orange sorties, or risk of Blue/Red war--is most responsible for the importance of uncertainty along the path with the highest value of modeling. In this case aircraft lost was computed to be the most sensitive outcome variable.

Since the path through the tree with the highest value of modeling is airstrike followed by no Red attack, and aircraft lost is the most sensitive outcome variable, the computer generates the following question designed to help identify missing events:

> Suppose you chose the alternative "air strike" and the event "no Red attack" occurs. Is there any event not yet included in the model that could cause "air loss" to increase?

In this application the commander was able to suggest an event that could lead to significantly larger aircraft losses. The event was that Red may have installed sophisticated anti-aircraft surface-to-air missle (SAM) batteries on the Island. If this were the case, the commander reasons that he would be likely to lose more planes than originally estimated. He therefore responds that there is such an event. The computer then requests a description and a short name for the newly identified event. Display 18 illustrates the appearance of the computer display screen during this structuring function.

If the user had been unable to identify an event that could cause aircraft losses to be significantly higher, the computer would have composed a similar question based on the second most sensitive outcome variable. Additional questions are composed in this way until a new event is successfully identified.

D. Event Testing

Events proposed for addition to the decision tree are tested to determine if adding the event to the tree might affect the decision. Displays 19 through 21 illustrate the testing function. The first question asks whether the decision maker would alter the decision if he were certain that the event would occur. If he would not, there is no point to adding the event to the model. Because the user answers "yes," however, a more sophisticated test is conducted.

The second test is to see if the event is sufficiently likely and important to affect the decision. The test consists of estimating the outcome that would result if the event were to occur, and then computing

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A COMPUTER-AIDED DECISION STRUCTURING PROCESS.(U)
JUN 79 M W MERKHOFER, B ROBINSON, R J KORSAN N00014-78-C-0175
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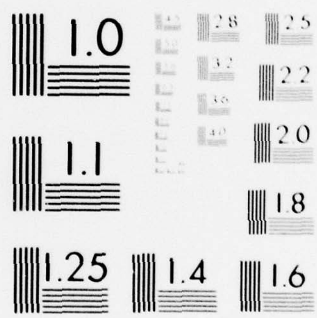
1.0
2.8
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3.2
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1.6

DECISION FACTOR IDENTIFICATION

SUPPOSE YOU CHOSE THE ALTERNATIVE "AIR STRIKE" AND THE EVENT "NO RED ATT" OCCURS. IS THERE ANY EVENT NOT YET INCLUDED IN THE MODEL THAT COULD CAUSE. . .

. . ."AIR LOSS" TO INCREASE?

(A VALUE OF 58 WOULD BE SUFFICIENT TO PRODUCE A DECISION SWITCH)

YES

WHAT DO YOU WISH TO CALL THIS EVENT?

RED SAM BATTERIES ON ONRODA

ACRONYM: SAM SITES

Display 18 DISPLAY FOR FACTOR IDENTIFICATION

DECISION FACTOR TESTING

IF YOU KNEW FOR SURE THE EVENT "SAM SITES" WOULD OCCUR, WOULD YOU PREFER THE ALTERNATIVE "BLOCKADE"?

YES

Display 19 TESTING DISPLAY-1

DECISION FACTOR TESTING

ROUGHLY, WHAT IS THE PROBABILITY OF THE EVENT "SAM SITES"?

0.3

SUPPOSE YOU CHOSE THE ALTERNATIVE "AIR STRIKE". IF YOU KNEW FOR SURE THE EVENT "SAM SITES" WOULD OCCUR, WOULD YOU CHANGE YOUR BEST ESTIMATE FOR THE EXPECTED VALUE OF THE OUTCOME "AIR LOSS"?

YES

IF YOU KNEW THE EVENT "SAM SITES" WOULD OCCUR, WOULD YOUR REVISED ESTIMATE FOR THE EXPECTED VALUE OF THE OUTCOME "F14" BE MUCH LOWER (0.0 - 0.8), LOWER (0.9 - 2.3), ABOUT THE SAME (2.4 - 6.1), HIGHER (6.2 - 10.2), MUCH HIGHER (10.3 - 48.0) ?

HIGHER

Display 20 TESTING DISPLAY-2

DECISION FACTOR TESTING

SUPPOSE YOU CHOSE THE ALTERNATIVE "BLOCKADE". IF YOU KNEW FOR SURE THAT THE EVENT "SAM SITES" WOULD OCCUR, WOULD YOU CHANGE YOUR BEST ESTIMATE FOR THE EXPECTED VALUE OF THE OUTCOME?

NO

****EVENT MAY AFFECT DECISION****

Display 21 TESTING DISPLAY-3

the probability the event would have to have for the commander to wish to switch decisions. If, when the worst possible outcomes are assumed, the required probability of the event necessary to cause the decision to switch is less than the estimated probability of the event, then that event should be added to the decision model. As the displays illustrate, testing the proposed event in this application verified that it should be added to the decision model.

E. Expanding the Decision Tree

As in the preliminary structuring phase, influence diagrams are used to simplify adding events to the decision tree. The computer draws the existing influence diagram and the newly proposed event and asks the user to draw the arrows required to add the event to the diagram. This is illustrated in Display 22. The user reasons that his decision to launch an airstrike or a blockade does not affect the probability of SAM sites, and whether or not SAM sites exist does not affect the probability of a Red attack. Therefore, the correct influence diagram contains no additional arrows.

When the user signals the program that he has completed modifications to the influence diagram, the computer checks to see that the diagram corresponds to a realizable decision tree.*

F. Input Estimation and Evaluation of the Expanded Tree

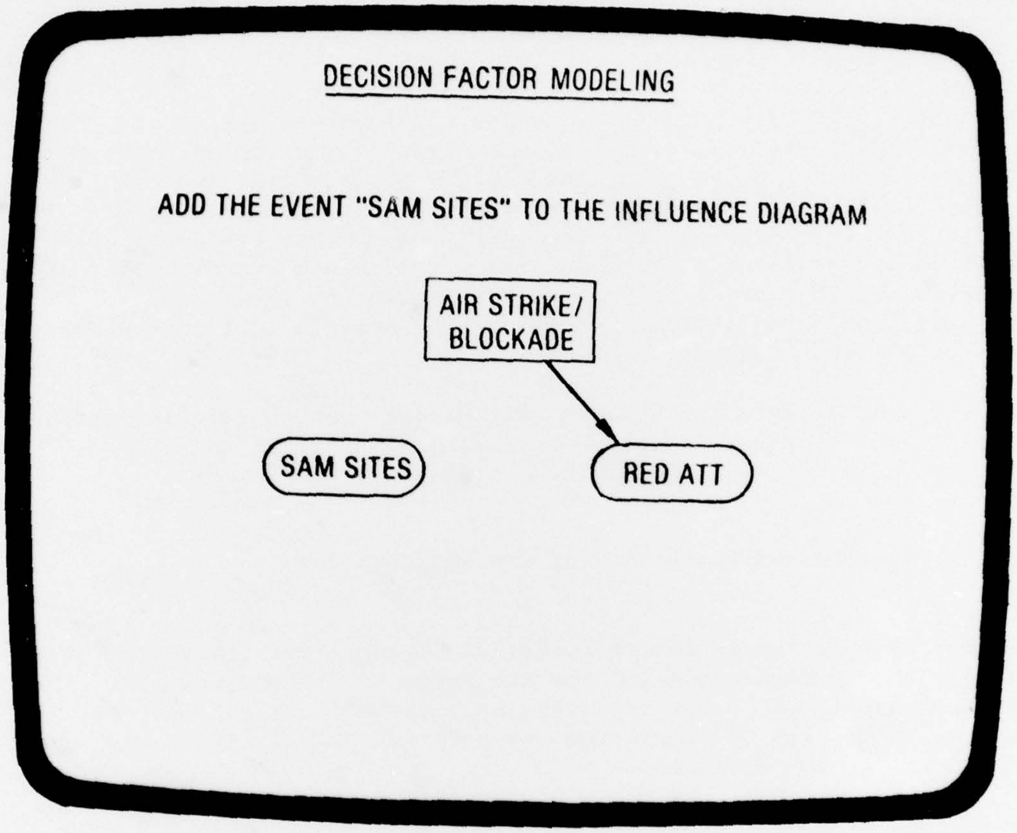
One iteration of the expansion cycle is now complete. To determine the solution to the expanded model and the value of further modeling, the user must supply the necessary additional probability and outcome estimates. Display 22 shows computer graphics for eliciting the additional outcome estimates.

Notice that it is not necessary to reassess outcomes for every path through the expanded tree. The only new estimates required are for those scenarios that involve an airstrike with SAM sites assumed. In this application, the user stated that he did not believe the event SAM sites would signficantly affect his estimate of ship losses, potential Orange sorties, or the risk of Blue/Red war. Therefore, revised estimates were supplied only for the outcome variable aircraft losses.

Display 23 shows the expanded decision tree. The preferred alternative now appears to be blockade. The path through the tree with the highest

---

*An error in diagram construction or a poorly formulated model (for example, an influence diagram with a loop) must be reformulated to be represented as a decision tree. The program checks the diagram and points out to the user any reasons that may prevent the diagram from being converted to a decision tree.



Display 22 INFLUENCE DIAGRAM DISPLAY

OUTCOME ESTIMATION

ENTER BEST (50%), LOW (10%), AND HIGH (90%) ESTIMATES FOR THE EXPECTED VALUE OF EACH OUTCOME VARIABLE BELOW. ASSUME THAT THE ALTERNATIVE CHOSEN IS "AIR STRIKE", THAT THE EVENT "NO RED ATT" OCCURS, AND THAT THE EVENT "SAM SITES" OCCURS.

AIR LOSS

F14	BEST ESTIMATE: 8	LOW ESTIMATE: 2	HIGH ESTIMATE: 9
A6	BEST ESTIMATE: 3	LOW ESTIMATE: 1	HIGH ESTIMATE: 4
A7	BEST ESTIMATE: 4	LOW ESTIMATE: 1	HIGH ESTIMATE: 6

Display 23 OUTCOME ESTIMATION DISPLAY

value of further modeling is now blockade followed by no Red attack. If additional structuring activity is to be undertaken, this is the scenario that should be expanded. The value of further modeling, however, has been reduced to about one-half of the previous value. Depending on the time and perceived importance of this decision, the user may choose to continue or terminate structuring activity at this point.

5. CONCLUSIONS AND RECOMMENDATIONS

The principal recommendation from this phase of the research is that research should be continued and directed toward first completing and then formally testing the decision structuring aid.

The recommendation for continuing development is based both on characteristics of the structuring process that suggest its potential value for aiding TFC decision making and on the results of preliminary applications. Important characteristics include:

- Flexibility -- The aid may be applied to virtually any unstructured decision situation.

- Efficiency -- The aid provides tests that reduce modeling effort by enabling factors that do not affect the decision to be identified before they are formally modeled.

- Realism -- Restrictive assumptions, such as assuming independence of uncertainties or a normal shape for probability distributions, are not required.

- Compatibility -- The aid may be used with prestructured models for estimating decision outcomes to produce an integrated decision aid. The integrated aid speeds up the structuring of a decision model and

shows how outcome calculators may be employed to identify an optimal course of action.

The limited experimental applications of the structuring process conducted so far have used both subjects who are familiar with and who are unfamiliar with decision analysis. Surprisingly, the decision tree models developed during these applications were simpler than models normally developed through the standard decision analysis methods. Nevertheless, in all cases the models developed and their solutions were readily accepted as adequate by the subjects. The time required was much less than that using traditional structuring approaches.

5.1 Principles for Testing

The detailed design for a testing program for evaluating the SRI decision structuring aid should be developed following completion of computer implementation. Based on the observed characteristics of the process and the results of preliminary applications, however, several principles for testing can now be identified.

Most important for the testing program will be specification of a criterion for evaluating the extent to which the aid improves decision making. An obvious approach is to design standard decision problems to be used for testing. Solutions to these standard problems might be based on the combined judgment of a panel of experienced naval commanders. Experiments could then measure the extent to which subjects using the aid come closer to the prescribed solution than do subjects not using the aid.

There are a number of problems with such an approach. First, the aid has been designed, by definition, for application to one-of-a-kind, unfamiliar decisions that have not been previously structured. Application to standardized decision problems may result in testing the aid on a class of problem for which it is not intended to be used.

An even more fundamental problem is the definition of a good decision. According to the discipline of decision analysis, a good decision is one that is consistent with the decision maker's information and preferences. The structuring process is designed to help a user identify a decision strategy that is consistent with his own subjective preferences and information. Thus, successful application of the aid can result in totally different decision strategies for individuals who have different information or preferences. Comparing the solution indicated by the structuring aid with the "right" solution generated by a panel of experts does not, therefore, directly measure the aid's ability to improve a decision maker's performance. The user could conceivably believe that the strategy derived through the use of the aid was better, given his state of information and preferences, than that produced by the panel of experts. We believe that a formal decision analysis resulting in a quantitative model of the type produced by the structuring process is the most effective way to generate a consistent decision strategy. Other methods, such as the use of a panel of experts, result in well-known group decision-making biases.

Once an adequate experimental design is selected, testing should attempt to answer several specific questions. Most importantly, if the aid fails to perform well, experimental design should indicate if the reason is

due to the user's inability to provide appropriate input information, if the difficulty is a more general problem with the decision-analysis modeling approach, if it is a problem related to the specific algorithm utilized in the SRI structuring process, or if it is a problem with the computer aid design.

A variable that may affect the value of the aid to a user is the user's proficiency in decision analysis techniques. Conseqeuntly, testing should attempt to identify whether the effectiveness of the aid depends strongly on the user's familiarity with decision analysis. Because the structuring process design lends itself to a very wide class of decision problems testing should also attempt to determine whether specific kinds of decisions are more effectively aided than others. If this is the case, then the characteristics that tend to make the aid very effective or ineffective should be identified.

Ease of use of the aid will be strongly influenced by input/output design, especially the use of graphics. Therefore, testing should attempt to identify what changes in computer aid design are needed to simplify its use. Finally, whatever criterion is adopted for measuring the ability of the aid to improve decision making, some attempt should be made to assess the extent to which the users feel that the aid is helping them. Specifically, does the aid help users to identify issues, does it help them to evaluate options, and, finally, do the users feel as though the aid helps them to formulate better decision strategies?

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Code 305
Navy Personnel Research and
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San Diego, CA 92152

Management Support Department
Code 210
Navy Personnel Research and
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San Diego, CA 92152

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Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

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Operations Research Department
Naval Postgraduate School
Monterey, CA 92940

Dr. Joseph Zeidner
Director, Organization and
Systems Research Laboratory
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

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Branch
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Code 5424
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Chairman, Department of Business
and Economics
Salisbury State College
Salisbury, MD 21801

Dr. Robert Brandenburg
ACCAT
Naval Ocean Systems Center
San Diego, CA 92152

Mr. Merlin Malehorn
Office of the Chief of Naval
Operations (OP 102X)
Washington, DC 20350

Mr. Harold Crane
CTEC, Inc.
7777 Leesburg Pike
Falls Church, VA 22043

Dr. S. D. Epstein
Analytics
2500 Maryland Road
Willow Grove, PA 19090

Dr. Amos Freedy
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. G. Hurst
University of Pennsylvania
Wharton School
Philadelphis, PA 19174

Dr. C. Peterson
Decisions and Designs, Inc.
8400 Westpark Drive
Suite 600
P. O. Box 907
McLean, VA 22101

Dr. George Pugh
Decision Science Applications, Inc.
1401 Wilson Boulevard
Arlington, VA 22209

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Applied Psychological Services
Science Center
404 East Lancaster Street
Wayne, PA 19087

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Integrated Sciences Corporation
1640 Fifth Streeet
Santa Monica, CA 90401